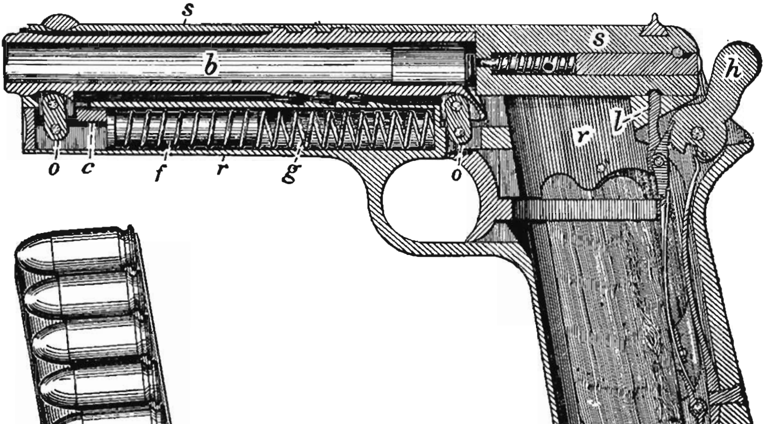


Fig. 263.

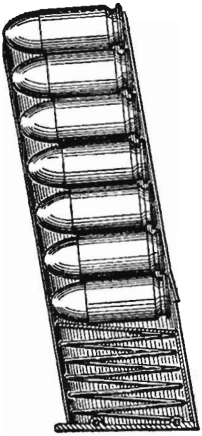


Fig. 264.

Fig. 265.

Colt Automatic Pistol, Caliber .45.

Page 544b
Back of Figs. 263-265
Faces Page 545

The forward extension of the receiver *r* contains the retractor spring *g* and has formed on its sides guides for the reciprocating slide *s*. The barrel *b* is attached to the receiver by two links *o*. The forward part of the slide *s* covers the barrel, and the rear part forms the breech bolt and carries the firing pin. Three lugs formed on the top of the barrel engage in notches in the slide and lock barrel and slide together. The slide lock *c*, a straight bar, holds the slide to the receiver. It passes through longitudinal slots in the sides of the receiver, and its ends are engaged in notches in the slide. The head of the retractor-spring follower *f* presses against a recessed seat in the middle of the slide lock *c*, and thus holds slide and barrel in firing position.

Operation.—The operation of the pistol when fired is as follows. The powder gases acting rearwardly against the bolt force the slide to the rear against the pressure of the retractor spring. The barrel, carried to the rear with the slide, revolves about the lower pivots of the two links *o*, its axis always remaining parallel to the top of the receiver. The downward movement of the barrel soon disengages it from the slide, but not until after the bullet has left the muzzle. The momentum acquired by the slide causes it to continue to the rear. Its rear end cocks the hammer *h*. An extractor carried by the slide withdraws the fired shell which, striking an ejector, is thrown out to the right through a slot in the slide. When the front of the bolt has passed to the rear of the top cartridge in the magazine this cartridge is forced upward into the path of the bolt by the magazine spring.

As the slide returns under the action of the retractor spring the bolt forces the top cartridge forward out of the magazine into the barrel in its lowered position, and then raises the barrel into its locked position for firing. A pull on the trigger now causes the cocked hammer to strike the firing pin and fire the cartridge.

When the last cartridge has been fired the slide remains to the rear, thus warning the soldier that the magazine is empty.

The safety lever, *l* Fig. 263, prevents movement of the trigger until the slide and barrel are in proper position for firing.

To load the first cartridge into the barrel, the rearward movement of the slide is produced by hand, the slide being grasped by the disengaged hand at the roughened surfaces on its sides, and pulled to the rear.

The necessity of using two hands to load the first cartridge into the barrel is one objection to the pistol as a military arm.

HOLSTER.—The pistol holster is a light steel frame covered with leather, and is arranged to be attached to the butt of the pistol in such a manner as to serve as a stock by means of which the pistol can be fired from the shoulder.

AMMUNITION.—The .45 caliber bullet, of lead with a cupro nickel jacket, weighs 200 grains. The charge of powder is 5.1 grains. The muzzle velocity of the bullet is 900 feet.

Five shots may be fired from the pistol in a second.

311. Modern Military Rifles.—The modern military rifle differs from its predecessors chiefly in caliber and in the use of the magazine. The caliber of the rifle in our service has been reduced from 0.45 to 0.30 of an inch, with an accompanying reduction in the weight of the bullet from 500 grains to 220 grains, and recently to 150 grains. The maximum pressure in the bore has been increased, with the change in caliber, from 25,000 pounds per square inch to 44,000 pounds.

INCREASED VELOCITY.—The increased pressure, better sustained along the bore by modern powders, produces in the lighter bullet a velocity very much greater than that attained in the rifles of larger caliber. The muzzle velocity of the bullet from the .45 caliber rifle was 1300 feet per second, while the present service rifle gives to the 220-grain bullet a muzzle velocity of 2200 feet, and to the 150-grain bullet a muzzle velocity of 2800 feet. At the same time, since the weight of the gun has not materially changed, the ratio of weight of bullet to weight of gun has greatly diminished. On this ratio principally depends the maximum velocity of free recoil of the gun for any given velocity of the projectile, see equation (4), page 275. We may consider the velocity of recoil, or better its square, as a measure of the shock of recoil. In the modern rifle the ratio of weight of bullet to weight of gun is diminished to such an extent that, even with the increased velocity of the bullet, the velocity of recoil is diminished. In consequence of the lighter shock of recoil on the soldier's shoulder, he is enabled to longer continue his fire without fatigue.

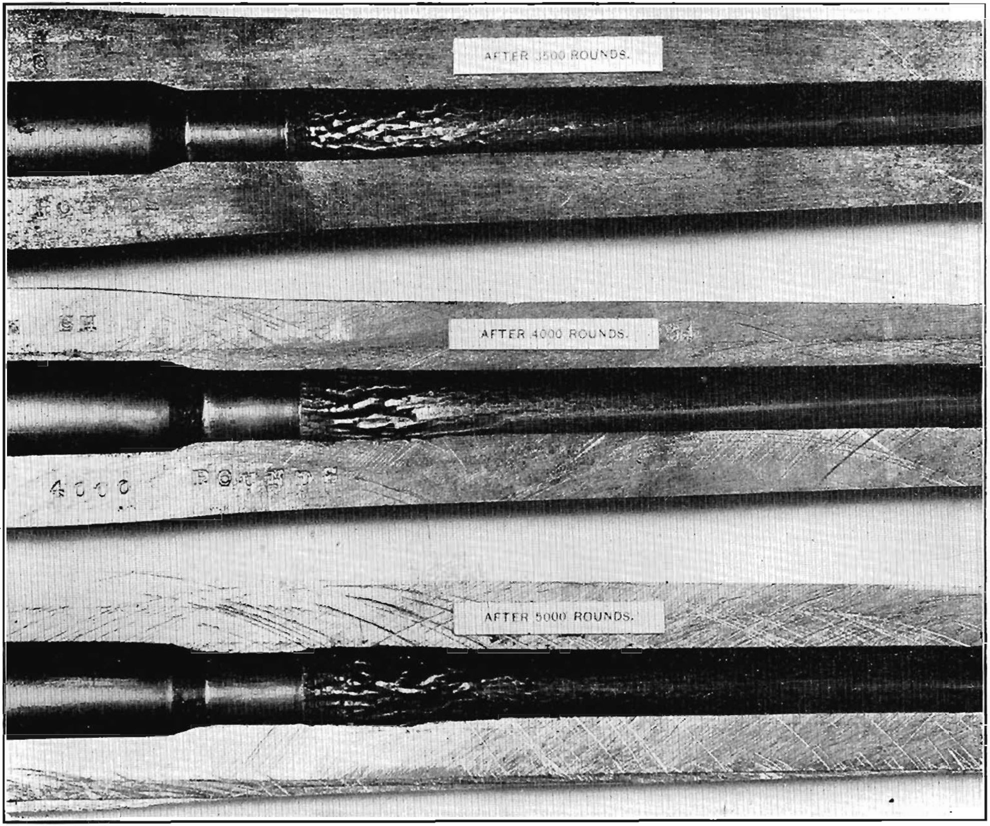


Fig. 266.—Erosion in Rifle Barrels.

Page 546b
Back of Fig. 266
Faces Fig. 267

Other Advantages. — The increased muzzle velocity increases the range and accuracy of the rifle and flattens the trajectory, thus increasing the danger space for any range. The increased velocity has been attained with a shorter barrel, thus diminishing the weight of the gun and facilitating the handling of the gun by the soldier.

The reduced weight of the bullet and of the charge of powder reduces the weight of the cartridge, thereby enabling the soldier to carry a greater number of cartridges on his person.

The Jacketed Bullet.—In order that the metal of the bullet shall not be stripped by the rifling as the bullet passes with high velocity through the bore, it is necessary to cover the soft lead of the bullet with a jacket of tougher material. The modern bullet is therefore composed of a lead core enclosed in a jacket made of cupro-nickel or of nickeled steel. The lead gives weight to the bullet and increases its sectional density, see page 458, while the tougher jacket enables the bullet to take the rifling without material deformation, and also gives to the bullet greater penetration in any resisting material.

The Magazine.—Ease and rapidity of fire are greatly increased by the use of the magazine. At the first introduction of magazine guns the cartridges in the magazine were considered as in reserve, to be used only in cases of emergency. The gun was habitually used as a single loader. In the latest weapons the filling of the magazine may be accomplished more readily than the insertion of a single cartridge into the barrel, since the cartridges are carried by the soldier in packets adapted to magazine loading only. Magazine fire is therefore used habitually, though the guns are adapted for single loading as well.

The mechanism of the magazine is usually arranged to lock the bolt of the gun open when the magazine is empty, so that in the excitement of battle the soldier may not continue to go through the motions of firing with an unloaded gun.

312. **Requirements.**—That the military arm may stand the rough usage incident to service in war it is essential that it be strongly constructed. Its mechanisms must be strong, simple, and easily dismantled for repair in the field without the use of

tools. The mechanisms must not be seriously affected by a moderate amount of rust or dust.

To lessen the chances of injury to the rifle as few of the parts as possible should project beyond its general outline. This latter consideration forms one of the objections to the attachment to military rifles of telescopic sights and other devices for increasing the accuracy of fire. The military rifle can rarely get the care necessary to keep the more delicate and more complicated sporting and target rifles in condition. Especially is this so in time of war when armies, those of the United States particularly, are largely composed of untrained volunteers most of whom have never previously carried a rifle. The arm that is put into their hands must be of such a character that it will be serviceable under almost all conditions, and as accurate as it may be made under this requirement.

Tests.—Before the adoption into our service of a rifle of new model the arm is subjected to tests as follows.

ENDURANCE TEST.—The arm is tested for endurance by firing from each of several rifles 5000 rounds, in forty lots of 100 rounds each and two lots of 500 rounds each.

At various stages of the endurance test the ballistic qualities of the arm are tested by firing for *velocity* and *accuracy*, and the working of the mechanism by tests for *rapidity of fire.*

DUST TEST.—The rifle, with the breech block closed, is subjected to a blast of fine sand for two minutes, first with the magazine empty and again with the magazine filled with cartridges. After each exposure to the blast the surplus sand is removed by blowing, by wiping with the bare hands only, and by tapping the butt and muzzle on the ground. The rifle must then be capable of operation in single loading and in magazine fire.

RUST TEST.—The rifle is thoroughly cleaned and all oil and grease removed by washing in soda water. The muzzle and chamber are tightly corked and the rifle is immersed in a saturated solution of sal ammoniac for ten minutes and then exposed to a damp atmosphere for 48 hours. The rifle must then be capable of operation as before.

DEFECTIVE CARTRIDGE TEST.—Cartridges cut through at the head, others cut through at the extractor groove, and others slit throughout their length are fired in the rifle.

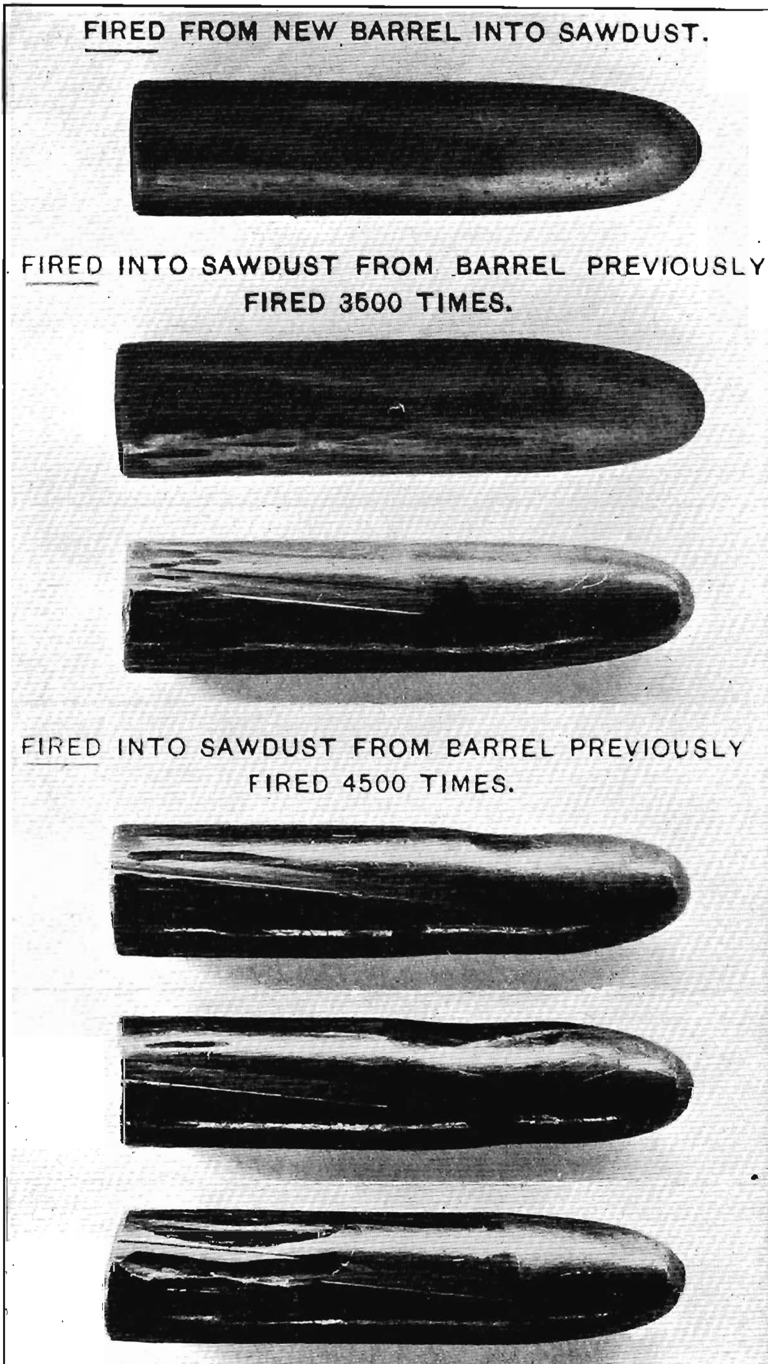


Fig. 267.—Effects of Erosion on Bullets.

Page 548d
Back of Fig. 267
Faces Page 549

Excessive Charge Test.—Five rounds are fired with cartridges loaded to produce a maximum pressure in the chamber one third greater than the maximum pressure attained in service.

313. Life of the Rifle. Erosion.—Although the rifle remains serviceable, as far as the operation of its mechanism is concerned, after endurance tests of 5000 rounds or more, its accuracy diminishes markedly after a number of rounds considerably less than 5000, the number depending on the conditions of the firing. With its accuracy seriously impaired the rifle ceases to be suitable for service. The service life of the rifle must therefore be measured by the number of rounds that can be fired from it with accuracy, and not by the number fired in tests for endurance.

The accuracy of the rifle is principally affected through the erosion of the barrel by the powder gases. The gases, highly heated and moving with high velocity under great pressure, attack the walls of the bore, which are probably softened by the great heat, and cut irregular channels in the metal, destroying the surface of the bore and the rifling. The erosion is greatest at the seat of the bullet immediately in front of the cartridge case, and extends forward into the barrel for several inches. Beyond this the walls of the bore are practically unaffected.

The effect of erosion is well shown in the enlarged photographs, Fig. 266, of rifle barrels from which 3500, 4000, and 5000 rounds have been fired.

When the erosion has become marked, the bullet is forced against an irregular surface and the metal of the bullet jacket, probably also softened by the heat, is unequally stretched on different sides, producing a decided eccentricity of the point of the bullet and great irregularity of the base. The sides of the bullet are deeply scored by the powder gases escaping past the bullet and by the irregularities of the bore.

In Fig. 267 are shown enlarged photographs of a service 220-grain bullet, model 1903, recovered after being fired into sawdust from a new rifle barrel, and of bullets fired from barrels that had been previously fired 3500 and 4500 times.

The deformation of the bullet is the chief cause of its inaccuracy. At the same time its muzzle velocity is reduced by the escape of the gases past the bullet in the bore.

Velocity and Pressure.—The erosive effect of the gases appears to depend more on their velocity than on the maximum pressure. Thus in tests that were made with the service rifle with 220-grain bullets fired with muzzle velocities of 2300 and 2200 feet, the maximum pressures in the two cases not being very different, the first appreciable falling off in accuracy occurred after 2000 rounds with the 2300-foot velocity and after 4000 rounds with the velocity of 2200 feet; and the accuracy after 7000 rounds with the lower velocity was better than after 4000 rounds with the higher.

Ammunition loaded to produce a muzzle velocity of 2300 feet was originally used in the service rifle, but after the above mentioned tests the muzzle velocity was reduced to 2200 feet and the accuracy life of the rifle increased from 2000 to 4000 rounds.

The 150-grain bullet recently adopted for the new rifle was intended originally to have a muzzle velocity of 2800 feet, the maximum pressure being considerably less than with the 220-grain bullet. It is doubtful whether, on account of the rapid erosion, this high velocity can be fixed as the standard.

Erosion, the cause of the reduction in the muzzle velocity in the small arm, is also the cause of the recent reduction of the muzzle velocities in the 10- and 12-inch seacoast guns from 2500 to 2250 feet.

314. The U. S. Magazine Rifle, Model 1903.—The present service rifle fulfils all the requirements enumerated in a previous paragraph as essential for a military rifle. As the Cadets of the Military Academy are armed with the rifle and familiar with its operation through daily use, an extended description of the weapon is not necessary here. Consideration of some of its parts may be of advantage.

Two views of the mechanism of the rifle, with bolt in closed position, are shown in Fig. 268.

The Receiver.—The receiver is that part of the gun that contains the breech closing bolt. It is held to the stock by the two guard screws, front and rear. The barrel is screwed into the front of the receiver.

Trigger Pull.—It will be observed that the rounded upper edge of the trigger bears against the bottom of the rear part of the

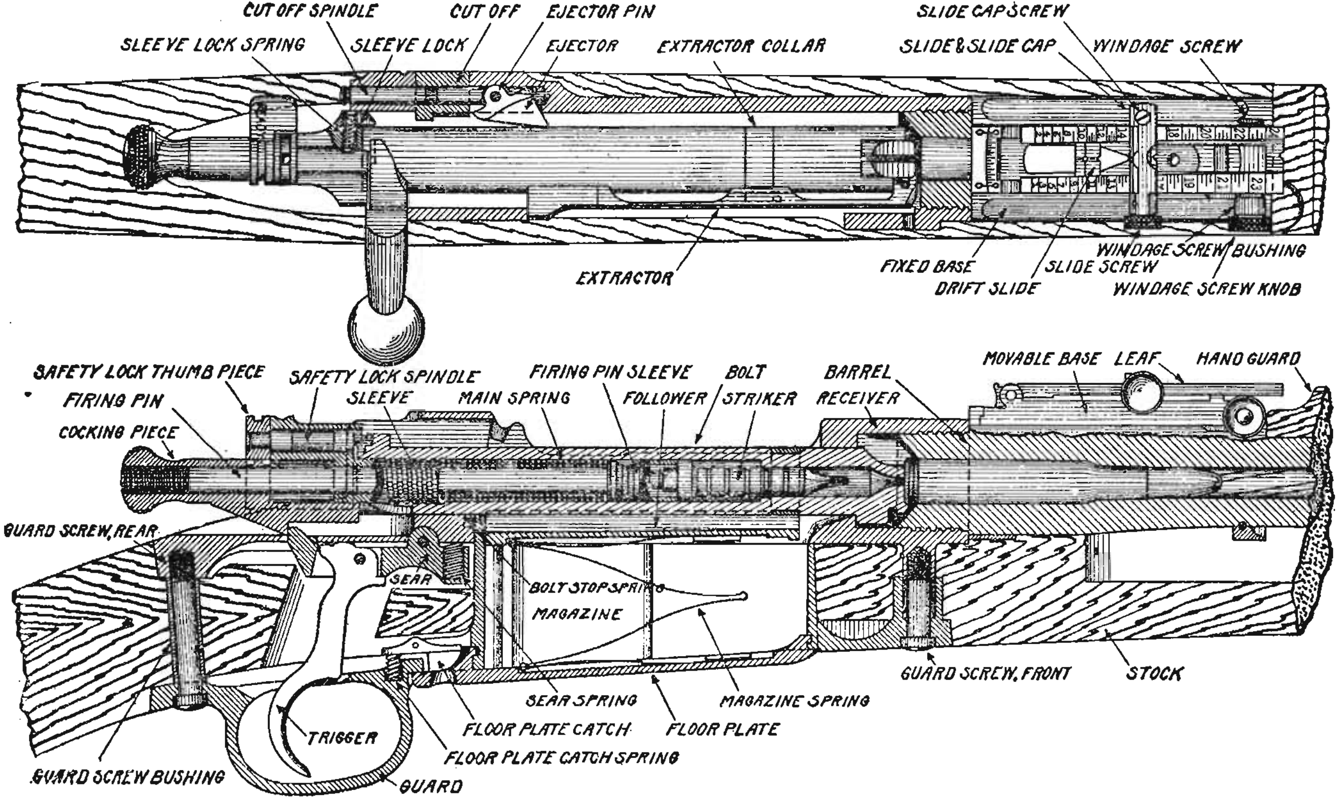


FIG. 268.—Mechanism of U. S. Magazine Rifle, Model 1903.

receiver, against which it is held by the pressure of the sear spring, the trigger being pivoted in the slotted sear. When the trigger is pulled it has comparatively free movement until the rear point, or heel, of the trigger bears against the receiver. The nose of the sear, its rear part which projects upward through a slot in the receiver, is by this movement partially withdrawn from the sear notch in the cocking piece. When the heel of the trigger bears against the receiver the trigger leverage is reduced and a short but more decided pull is required to further withdraw the sear from the sear notch. The purpose of the first movement of the trigger, against slight resistance, is to prevent accidental discharge of the piece as the soldier first feels the trigger, and to increase the accuracy of fire by enabling the soldier to partially withdraw the sear while aiming, and to complete its withdrawal at the proper moment by a slight movement of the finger.

Cams.—In the operation of the mechanism the most decided resistances are encountered in the compression of the mainspring and, at times, in the insertion of a cartridge into the barrel and in the extraction of the fired shell. In order that these operations may be accomplished with the least fatigue to the soldier they are all performed by means of cams.

The mainspring is partially compressed in the movement of unlocking the bolt by the action of a cammed surface of the bolt against the cocking cam on the firing pin, and the compression of the spring is completed on the closing of the bolt by the action of the two locking lugs at front end of bolt against the cammed locking shoulders in the receiver. The cammed movement of rotation also forces the cartridge to its seat in the chamber. In the rotation of the bolt in opening, the extracting cam at upper end of bolt handle works against a cammed surface in the receiver and moves the bolt slightly to the rear, starting the fired shell from the chamber.

The Barrel.—The rifling of the barrel consists of four grooves 0.004 of an inch deep. The grooves are three times as wide as the lands. The twist is uniform, one turn in 10 inches, and right handed. The length of the barrel, measured from end to end, is 24.206 inches, a length that permits the use of this arm by the cavalry, and makes their fire as efficient as that of the infantry.

Formerly the cavalry were provided with carbines, short guns with the same mechanism as the longer rifle and using the same ammunition.

The muzzle of the barrel is rounded to protect the rifling. Any irregularity of the muzzle end of the bore will seriously affect the accuracy of the arm by causing unequal pressure on the sides of the bullet as it is about to leave the bore.

315. THE SIGHTS, MODEL 1905.—The sight seats or bases for front and rear sights are bands that encircle the barrel, to which they are fixed by splines and pins. This method of attachment is preferable to the method formerly employed of screwing the sight seats directly to the barrel, as the sights are now more securely held and there is less likelihood of their adjustment being disturbed.

The windage screw, Fig. 268, which gives the movement in deflection to the rear sight, is acted on by a spring which prevents lost motion due to wear in the parts of the rotating mechanism.

Each division or point of the deflection scale of the rear sight corresponds to a lateral deviation of 4 inches in 100 yards.

The leaf of the sight is graduated for elevations from 100 to 2500 yards, the sight for the latter range being taken through the notch on upper end of leaf.

With the leaf down the sights are set at 400 yards, battle range, at all positions of the slide on the leaf.

In the movement of the slide up the leaf, the drift slide, Fig. 268, in which are cut the sighting notches and peep, follows a drift curve cut in the leaf and thus compensates for the lateral deviation of the trajectory from the line of sight as adjusted on the piece. Explanation of the drift and of the adjustment of the line of sight will be found in a later paragraph entitled *Deviation*.

The front sight is fitted in a stud that before being screwed to its seat is adjusted laterally to its proper position on the individual rifle. The proper adjustment is obtained by actual firing with each rifle. The firings are done by expert marksmen over a covered 200-yard range provided at the armory.

The sight radius of the piece, the horizontal distance between the point of the front sight and the rear edge of the notch or peep of the rear sight, is 22.3254 inches.

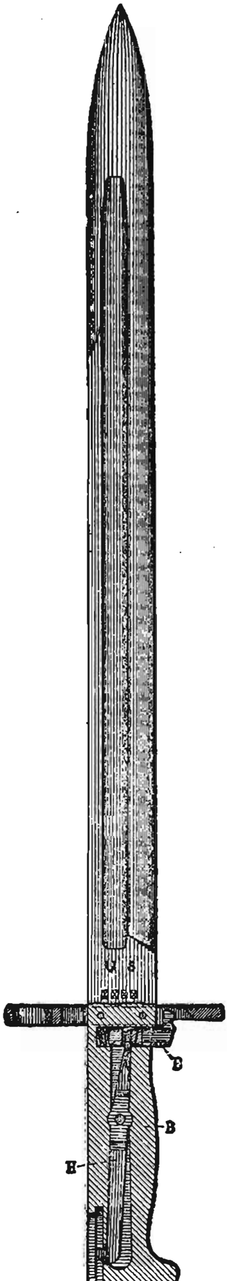


FIG. 269.

RAPIDITY OF FIRE.—With single loading, 23 aimed shots have been fired from the rifle in one minute, and with magazine fire, 25 shots in one minute. With the rifle held at the hip, 27 unaimed shots, loaded singly, have been fired in one minute, and with magazine fire, 35 shots.

THE BAYONET.—The tang *B* of the bayonet, Fig. 269, is of one piece with the blade. In a recess in the tang is mounted the catch *H* which engages under the bayonet stud on the gun, locking the bayonet to the gun; and the catch *E* which secures the bayonet in its scabbard by engaging a hook provided in the scabbard. Either catch is released by pressure on the thumb piece *E*.

Appendages.—Among the appendages provided for the care of the piece is a *bullet jacket extractor*, Fig. 270, a cylindrical steel plug rifled on the exterior to fit the bore.

FIG. 270.

This is pushed down the bore from the muzzle until it rests on the bullet jacket, which may then be forced out of the barrel.

A headless shell extractor consists of a steel plug, Fig. 271 of the general shape of the

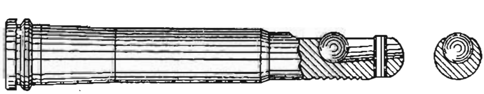


FIG. 271.

inside of the cartridge case, with a head like that of the cartridge. A steel ball rolls freely in a groove at the point, the groove being inclined outward toward the point. The extractor is roughened on the side opposite the groove. The extractor is pushed into the headless shell by the bolt of the gun, the gun being held with the muzzle up. The muzzle of the gun is then pointed down and the bolt withdrawn, extracting the extractor and the headless shell.

An aiming device is also provided for purposes of instruction in aiming. It consists of the circular steel clip *a*, Fig. 272, which embraces the gun in rear of the rear sight and supports the standard *b* to which the cage *c* may be fixed at any desiréd height. The cage contains a reflector so arranged that the instructor sees in the reflector the images of the gun sights and of the object aimed at. He may therefore correct the soldiers' aim.

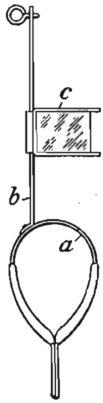


Fig. 272.

A cleaning thong and brush are contained in a metal case carried in the butt of the stock. The case is arranged to contain also a quantity of oil and a metal oil-dropper. A brass cleaning rod, a steel front sight cover, and a suitable screw driver are provided with each piece.

316. Deviation. Drift.—The rifle has a right-handed twist. The drift proper is therefore to the right. But at the moment that the bullet leaves the bore the muzzle of the gun is actually pointed to the left of its aimed position. The movement of the muzzle is probably due to vibrations of the barrel caused by the passage of the bullet through the bore. The barrel being held firmly at the bands the vibrations will take place about these points as nodes. The vibratory movement of the barrel is such that at the moment that the bullet leaves the bore the muzzle is pointed to the left of its aimed position.

The horizontal deviation of the bullet from the axial plane of sight is therefore the resultant of the drift due to the rifling and the deviation due to the vibration of the barrel. Following custom, we will call the resultant horizontal deviation the drift.

As determined by experimental firings the drift of the 220-grain bullet, fired from the service rifle, is to the left of the axial plane of sight up to a range of 850 yards, and beyond that range the drift is to the right.

In order to minimize the deviation at the most important ranges the drift slot in the leaf of the model 1905 sight is so cut as to make the trajectory cross the adjusted line of sight at a range of 1530 yards. Within that range the drift is to the left of the line of sight, its maximum value being 1.8 inches at the range of 1200 yards. After the trajectory crosses the line of sight the drift is to the right and increases rapidly from 1.1 inches at 1600 yards to 39.4 inches at 2500 yards.

VERTICAL DEVIATION.—The angles of elevation of the rifle as determined from actual firings at different ranges are all greater than the computed angles of elevation for the ranges. This indicates that at the moment that the bullet leaves the bore the position of the muzzle due to the vibratory movement of the barrel is below as well as to the left of its aimed position. The difference between the observed and computed elevations increases with the range, as it should since the effect of a constant difference of the angles will be less as the range increases.

The .22-caliber Gallery Practice Rifle.—The gallery practice rifle differs from the U. S. magazine rifle, model 1898, known as the *Krag-Jorgensen* rifle, only as to the barrel and the receiver. The barrel of the gallery practice rifle is a .22-caliber rifled barrel adapted to fire commercial .22-caliber, rim-fire, short or long cartridges. The barrel is issued assembled with a suitable extractor to a modified receiver. Any model 1898 rifle may be converted into a gallery practice rifle by dismounting the .30-caliber barrel and receiver and mounting in their stead the .22-caliber barrel and receiver.

With .22 caliber long cartridges, a range of 50 feet requires the sight to be set at 100 yards, and a range of 100 feet requires a sight setting of 225 yards.

AMMUNITION FOR THE .30-CAL. MAGAZINE RIFLE.

317. The Ball Cartridge.—The ball cartridge, Fig. 273, consists of the cartridge case, the primer, the charge of powder, and the bullet.

THE CARTRIDGE CASE.—The cartridge case is made from a circular disk of brass cut from a flat ribbon 0.13 of an inch thick. The disk is first bent into the form of a cup and then drawn out in successive operations by being forced by punches through dies successively diminishing in diameter. In each draw press the length of the cartridge is increased and its diameters and thickness of wall diminished. Six draws are required to bring the cartridge to the desired size. After the cupping operation and after

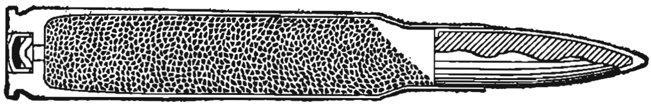


FIG. 273.

each of the first four draws the case is softened by annealing, which removes the brittleness of the metal caused by the drawing process. The cases are trimmed as required. The head of the cartridge case and the primer pocket are formed in a press. The mouth of the case is then annealed and the reduction of the neck and shoulder is accomplished in three operations in another press. The extractor groove is turned in the head, and the vent is punched through the bottom of the primer pocket.

BODY.—The body of the cartridge is of greater diameter than the rifled bore of the gun, in order to provide the necessary chamber space in the shortest practicable length. The enlarged body is a disadvantage in that it increases the bulk of the cartridge, and requires a larger chamber in the gun and greater thickness in the working parts of the gun. But in the present development of powders it has not yet been possible to produce from a cylindrical cartridge of reasonable length the desired ballistics for the rifle.

HEAD SPACE.—The space in the rifle between the head of the bolt and the surface against which the cartridge bears is called the head space. The head space in the rifle is of a length to allow proper clearance between the bolt and the head of the cartridge when the cartridge is fully inserted in the chamber. The head of the cartridge should always occupy the same position in the rifle, in order that the blow of the firing pin on the primer may be uniform, thus reducing the chances of misfires and punctured primers.

In order that the position of the primer in the gun shall vary the least the head space should be as short as possible, that is, the bearing surface of the cartridge should be close to the head of the cartridge, since in the manufacture of the cartridge the variations in a short dimension are likely to be less than in a longer one.

The cartridge with flanged head, Fig. 274, used in former service rifles, has an advantage over the present cartridge in this respect. The head space with the flanged cartridge measured from the seat for the front edge of the flange, was about $\frac{1}{10}$ of an inch

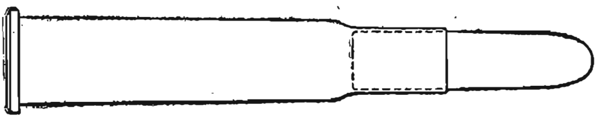


Fig. 274.

long, while the head space in the present rifle which is measured from the seat for the sloping shoulder of the cartridge, is nearly two inches long. In addition the bearing surface of the present cartridge is sloped, so that more extensive variations in the position of the head of the cartridge are likely to occur.

The Primer.—The primer, Fig. 273, consists of the cup, the anvil, and the percussion composition. A pellet of moist percussion composition is put into the cup which is previously shellacked so that the composition will adhere. A shellacked disk of paper is pressed in tightly over the composition to keep out moisture. The anvil of hard brass is then forced into the cup. The primers are dried for several days in a dry house.

The cup of the primer is made of gilding metal, an alloy of copper much softer than the brass of the cartridge case. The metal of the cup must be sufficiently soft, and of the proper thickness, to permit a large part of the blow of the firing pin to be transmitted to the percussion composition, thus insuring explosion of the primer. At the same time the metal must be sufficiently hard to resist puncture by the firing pin. The firing pin strikes the primer with an energy of about 17 inch-pounds.

The priming composition is as follows:

Chlorate of potash,	632 parts
Sulphide of antimony,	320 parts
Ground glass,	212 parts
Sulphur,	110 parts

The finely pulverized ingredients are thoroughly mixed wet, and the composition is always handled wet, in which condition it is safe to handle. The composition is called the *H 48* composition.

This composition is safe, sufficiently sensitive, and emits a large body of flame. The large body of flame makes the composition superior for use with smokeless powders to the fulminate of mercury formerly used in all primers and still largely used in the primers in sporting cartridges and others.

The primer is seated slightly below the head of the cartridge in order to diminish the liability to accidental explosion of the cartridge in handling.

THE POWDER CHARGE.—The powder charge consists of about 51 grains of nitroglycerine powder. The weight of powder required to produce the muzzle velocity of 2800 feet varies in different lots of powder. The weight of charge therefore varies slightly in different cartridges.

318. Bullets.—The core of the bullet, Fig. 273, is an alloy of 16 parts of lead and one part of tin. The jacket, of cupro-nickel, is drawn from a disk in the same manner as the cartridge case. The lead slug is forced into the jacket, the point of the bullet shaped in a press, and the rear end of jacket turned squarely over the base of the bullet.

The 220-grain bullet is shown in Fig. 275, and the recently adopted 150-grain bullet in Fig. 276. The 220-grain bullet had a muzzle velocity of 2200 feet, the maximum pressure in the bore of the rifle being about 49,000 lbs. The 150-grain bullet is given a muzzle velocity of 2800 feet with a maximum pressure of 45,600 pounds. The great increase in the muzzle velocity makes the trajectory of the lighter bullet very much flatter than that of the 220-grain bullet, and thus correspondingly increases the accuracy of the rifle. It might be expected that the lighter bullet would suffer greater retardation in flight from the resistance of the air, but this bullet with its sharp point encounters less resistance than the heavier bullet with its rounded point. Greater accuracy at all ranges therefore results from the lighter bullet, with its higher velocity and sharp point.

FIG. 275.

FIG. 276.

The *bearing surface* of a bullet, that part of the bullet that comes in contact with the walls of the bore, should end abruptly, in order that as the bullet leaves the muzzle the bearing against the walls of the bore will cease at the same instant on all sides, and the bullet will not be deflected by the longer contact of any one point with the walls of the bore. The bearing surface of the service bullet terminates at the base. The base of the bullet should therefore be square with the axis, and the edge of the base should be as sharp as the metal of the jacket will permit.

In Fig. 277 is shown in full size a bullet recently tested. The bullet, of copper, weighed 175 grains. The bearing surface began about $\frac{3}{4}$ of an inch from the point and extended to about $\frac{1}{4}$ of an inch from the base, terminating on the rear slope of the bullet, the diameter of the base being less than the caliber. In tests for comparative accuracy at 500 yards the radius of the circle of shots was 4.2 inches for the 150-grain service bullet, 5.6 inches for the 220-grain service bullet, and 25.6 inches for the experimental copper bullet. On examination of the copper bullets, recovered after firing, the marks of the rifling were found extending farther to the rear on one side of the bullet than on the others. The difference in length of bearing on the different sides is sufficient to account for the inaccuracy.

FIG. 277.

319. The Blank Cartridge.—The bullet of the ball cartridge guides the cartridge from the magazine into the chamber of the rifle. In order that blank cartridges may be loaded from the magazine, a hollow paper bullet, Fig. 278, replaces the metal bullet

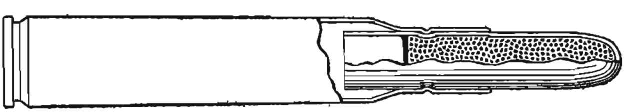


FIG. 278.

of the ball cartridge. The paper bullet is charged with 5 grains of E. C. powder held in place by a drop of shellac. The bullet is made by rolling a strip of paper into a tube of proper length, the end of the tube being afterwards closed into the rounded head by pressure in a machine. The strip of paper that forms the tube is gummed only on the outside edge so that the charge may readily burst the bullet at the muzzle of the gun. If the paper were gummed over its entire length the bullet would be so stiff that it might act as a rocket and do injury at some distance from the muzzle.

The propelling charge in the cartridge case is 10 grains of E. C. powder.

The blank cartridge is made $\frac{1}{10}$ of an inch shorter than the ball cartridge, to prevent the accidental assembling of a ball cartridge into a clip with blank cartridges. The machine in which this operation is performed is adapted for cartridges of one length only.

The Dummy Cartridge.—In order that the dummy cartridge, Fig. 279, may be readily distinguished from the ball cartridge both.

FIG. 279.

by sight and touch, the case of the dummy cartridge is tinned and corrugated, and three holes are bored through the bottoms of the corrugations. These are means intended to diminish the chances of the insertion of a ball cartridge in the rifle when drilling with dummy cartridges.

The Guard Cartridge.—The long range of the bullet of the ball cartridge and its great penetrative power render the ball cartridge unsuitable for the use of guards in times of peace, and for use in cities or other crowded places at times of riot and dis-

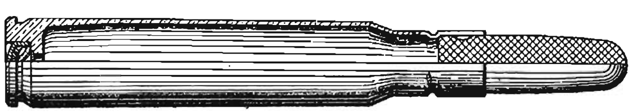


FIG. 280.

turbance. The guard cartridge, Fig. 280, is provided for these uses. The unjacketed lead bullet weighs 117 grains and is given a velocity of 1150 feet. The cartridge gives good results at 100 yards and has sufficient accuracy for use at 150 and 200 yards.

The lead bullet is deformed on striking and has little penetrative power, so that it is not likely to cause injury at a distance to innocent persons.

320. Proof of Ammunition.—Ammunition is proved by velocity and accuracy tests made with the arm in which the ammunition is to be used. Service rifle cartridges are also tested to determine whether they are waterproof.

VELOCITY TEST.—The velocity is measured at 53 feet from the muzzle, the first velocity screen being placed 3 feet from the muzzle and the two screens 100 feet apart. The mean velocity of 10 shots must not differ more than 15 feet from the standard.

ACCURACY TEST.—The accuracy test for rifle ammunition consists of several series of 10 shots each fired at a target 500 yards from the muzzle. The gun is fixed in a rest. The target is a heavy steel plate about 20 feet square, painted white and marked with horizontal and vertical black lines 2 feet apart.

The horizontal and vertical coordinates of each shot mark are measured from a convenient origin. The means of the horizontal and vertical coordinates are respectively the horizontal and vertical coordinates of the *center of impact.*

The distance of each shot from the center of impact is measured and the mean of these distances is the *mean radius* of the group of shots, or, as it is sometimes called, the radius of the circle of shots.

The mean of the vertical distances of the shots from the center of impact is the *mean vertical deviation,* and the mean of the horizontal distances from the center of impact is the *mean horizontal deviation.*

In the proof of ammunition the mean horizontal deviation is not measured, as the horizontal deviation depends upon the atmospheric conditions rather than upon the ammunition.

The results of recent comparative tests of the 220-grain and 150-grain bullets in the service rifle are shown in the following table.

Bullet.	Charge, Grains.	Pressure, Lbs.	Velocity, f. s.		Accuracy 500 Yards.		Penetration 500 Yards, Inches.
			Muzzle.	1000 Yards.	Rad.	M.V.D.	
220-grain, 1903.	44	49000	2200	980	5.6	4.2	23.3
150-grain, 1906.	51	45000	2730	1130	4.2	2.5	32.5

Equipment for Accuracy Test.—As it would often be most inconvenient to make on the target the measurements necessary for the determination of the mean radius and deviations of a group of shots, the ammunition proof range is provided with a *camera obscura* in a building in front and to one side of the target and near it. The lens of the camera forms an image of the target on a paper facsimile of the target constructed to the proper scale so that the lines of the image coincide with the lines of the target facsimile. An observer in the camera marks with a pencil the image of each shot mark made on the target, and the desired measurements are then conveniently made from the paper facsimile.

WATERPROOF TEST.—Cartridges from each lot manufactured are immersed in water at a depth of 8 inches for a period of 24 or 48 hours, and are then tested for velocity. There must be no falling off in velocity due to the entrance of moisture into the case.

CHAPTER XVI.

MACHINE GUNS.

321. Service Machine Guns.—The machine guns in our service are the Gatling machine gun and the Maxim automatic machine gun. The guns are of the same caliber as the infantry rifle and use the same ammunition.

In the Gatling machine gun the operations of loading, firing, and extracting the empty shell are effected through mechanisms actuated by a crank. The crank is turned by the gunner at a rate to produce any desired rapidity of fire. The greatest efficiency is obtained from the gun at a rate of fire of 600 rounds per minute. In an emergency this rate can be greatly increased.

In the Maxim automatic machine gun the operating mechanism is actuated by the recoil, so that after the first shot is fired the firing continues without effort on the part of the gunner as long as the trigger is pressed. The rate of fire from the gun depends upon the condition of the barrel and mechanism. In a new gun 250 cartridges in a single belt are fired at the rate of 650 shots a minute. After 8000 rounds this rate is reduced to about 325 shots a minute. In the continuous firing of 1000 rounds the rate of fire from a new gun is about 400 rounds a minute.

The Gatling gun has the advantages of a more rapid rate of continuous fire, and of a complete control of the rate of fire at all times. The fire of the automatic gun is however sufficiently rapid, the aiming is not interfered with by the operation of a crank, and the gun is lighter and more readily transported. It has therefore been adopted as the principal machine gun for our service.

Machine gun fire has recently become of such importance in battle that a machine gun platoon, armed with two automatic machine guns, is organized in each battalion of infantry and in each squadron of cavalry, so that six machine guns now accompany each regiment into the field.

The Gatling Machine Gun.—Fixed to a central shaft *S*, Fig. 281, are the ten .30-caliber rifled barrels *B* held in the barrel

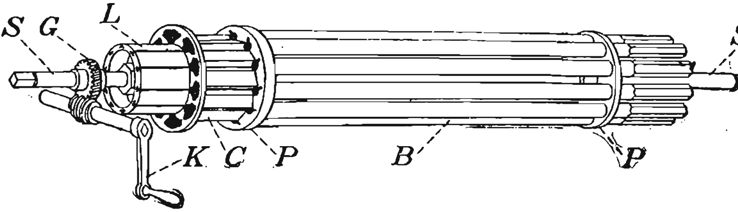


FIG. 281.

plates *P*; the carrier block *C*, provided with grooves which receive the cartridges successively and guide them into the barrels, the lock cylinder *L*, provided with guide slots in which the breech blocks for the barrels slide to close and open the breech; and the worm wheel *G*, by means of which the shaft and attached parts are rotated. The shaft is supported at each end in a frame, the sides of which also support the shaft of the rotating crank *K*.

The parts behind the rear barrel plate are completely inclosed in a cylindrical bronze casing which keeps out dust and protects the operating parts against injury. Within the casing is a hollow cylinder, called the cam cylinder, on the interior surface of which a continuous cam groove is cut.

The breech bolt, Fig. 282, one for each barrel, carries the firing

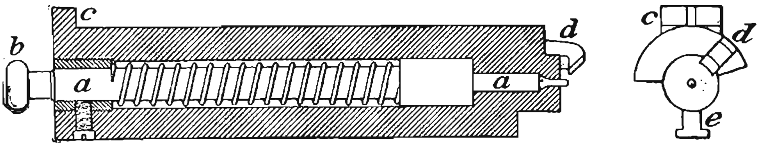


FIG. 282.

pin *a*, and its spring, and the extractor *d*. The guide rib *e* at the bottom of the bolt engages in a guide slot of the lock cylinder, *L* Fig. 281. The lug *c* on top of the bolt engages in the cam groove cut in the walls of the cam cylinder.

The cam groove, represented in Fig. 283 as though visible through the casing and cam cylinder, extends continuously around the interior of the cylinder. The top and bottom parts of the groove, *a* and *b*, follow lines cut from the cylinder by planes at right angles to its axis. These parts of the groove are joined by the inclined parts *cd*. The cam cylinder is fixed to the casing and does not revolve.

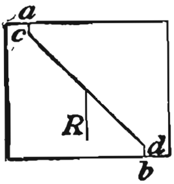


FIG. 283.

322. OPERATION.—As the lock cylinder, *L* Fig. 281, rotates with the barrels in a clockwise direction, the uppermost breech bolt is in its rearmost position, being held there by the lug *c* of the bolt moving in the circular part *a* of the groove. While the bolt is in this position a cartridge is placed by the feed mechanism in the top groove of the carrier block *C* in front of the bolt. As the bolt in its rotation moves downward on the right side it is

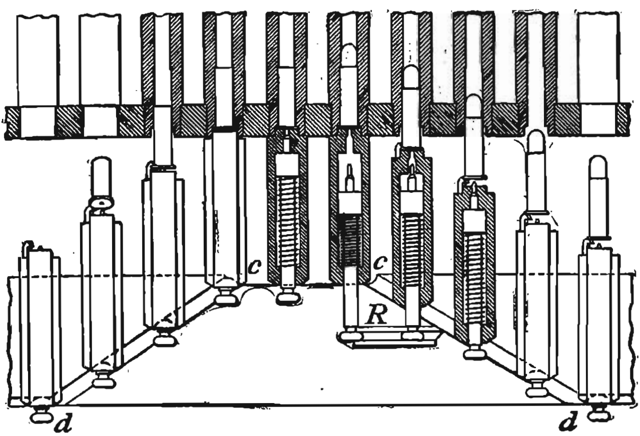


FIG. 284.

moved forward by the cam groove *cd* and pushes the cartridge into the barrel. During this movement the cocking head of the firing pin, *b* Fig. 282, is caught by a grooved rib, *R* Figs. 283 and 284, and the firing pin is prevented from moving forward with the bolt. The method of operation will be understood from Fig. 284, which shows a development of the cam groove and rotating parts. The lines *dd* and *cc* in Fig. 284 represent respectively the developments of the parts *a* and *b* of the groove as shown in Fig. 283.

When the barrel is in its lowest position the head of the firing pin leaves the rib *R*, and the firing pin, under the action of its spring, strikes and fires the cartridge. As the breech bolt moves upward on the left side it is drawn to the rear by the cam groove, extracting the fired shell from the barrel and ejecting it to the left through a slot in the casing.

THE FEED.—A hopper is formed in the top of the bronze casing immediately over the carrier block, *C* Fig. 281 and *e* Fig. 285. The device, called the Bruce feed, for feeding cartridges to the gun, is fixed in a socket at the mouth of the hopper. Pivoted on the standard, *ac* Fig. 285, is a swinging piece *b*, provided with two flanged grooves which engage the heads of the cartridges: by the flange of the 1898 cartridge, and by the groove of the 1903 cartridge. The grooves in *b* are quickly filled by stripping the cartridges from the paper boxes in which they are packed. The cartridges from one of the grooves in *b* pass immediately through the groove in *c* and are fed one at a time to the carrier block *e* by the wheel *d* which is caused to revolve by the carrier block. When one of the grooves in *b* is empty the weight of the cartridges in the other groove causes the piece *b* to swing to one side and bring the full groove over the groove in *c*.

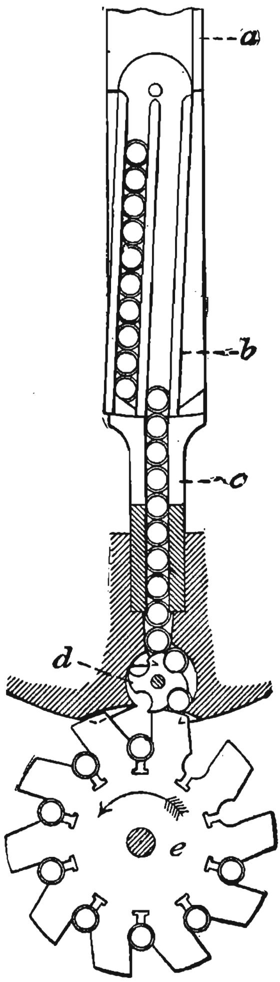


FIG. 285.

MOUNTS.—The Gatling gun is mounted, for field service, on a shielded wheeled carriage with limber. When mounted in the casemates of permanent or temporary fortifications for use in repelling landing parties and in protecting the land approaches, a fixed mount is provided.

Blank Cartridge for Gatling Gun.—When the blank cartridge for the infantry rifle is used in the Gatling gun the blunt end of

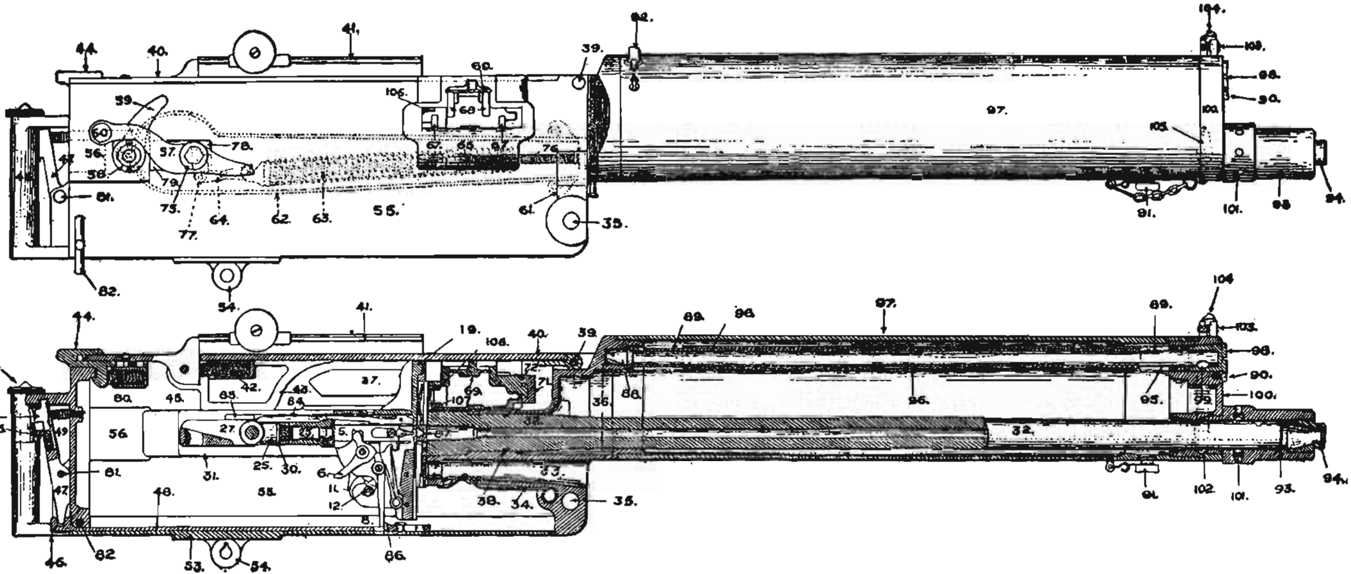


FIG. 286.—Maxim Automatic Machine Gun.

the paper bullet often catches on a shoulder at the rear end of the barrel, thus preventing insertion of the cartridge and causing the mechanism to jam.

A special blank cartridge is therefore made for the gun. The cartridge case is extended to the length of the complete ball cartridge and, after the insertion of the powder charge, the mouth of the case is closed into the rounded form of the point of the 220-grain bullet.

323. The Maxim Automatic Machine Gun.—The Maxim automatic machine gun has a single barrel, and the recoil of the barrel and attached mechanism is utilized to perform the operations necessary in continuous firing.

The barrel, 32 Fig. 286, is inclosed in a cylindrical water jacket 97, and slides in its bearings in stuffing boxes at each end of the water jacket. Fixed to the rear end of the water jacket is the breech casing 55, a rectangular steel box that incloses the operating mechanism and provides means, 35 and 54, for the attachment of the gun to its mount.

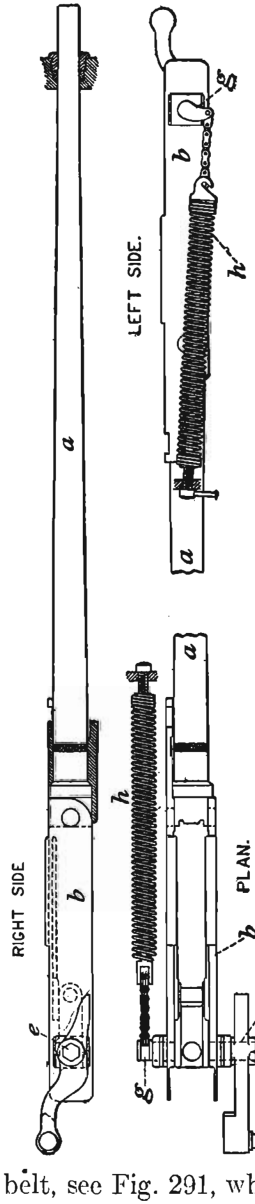


FIG. 287.

METHOD OF ACTION.—The barrel and the breech mechanism recoil together until after the bullet has left the bore. When the barrel has reached the end of its recoil the breech mechanism continues to the rear, opens the breech, and extracts the fired shell; and, returning under the action of a spring, inserts a new cartridge in the barrel and fires the piece. These actions are repeated as long as the trigger is pressed.

The cartridges are fed to the gun in a belt, see Fig. 291, which is automatically drawn through the feed mechanism above the breech in such manner as to present a new cartridge after each discharge.

RECOILING PARTS.—The recoiling parts, Fig. 287, comprise the barrel *a*, the two recoil plates *b* fixed to the breech of the barrel, the operating crank shaft *e* fixed in bearings in the recoil plates, and the breech mechanism which slides between the recoil plates and is operated by means of the crank shaft *e*.

The recoil plates slide in grooves provided in the sides of the breech casing 55, Fig. 286. The left recoil plate extends to the front of the breech and operates the feed mechanism above the barrel. The crank shaft 75 projects on both sides through slots 79 in the casing. The movement of the recoiling parts to the

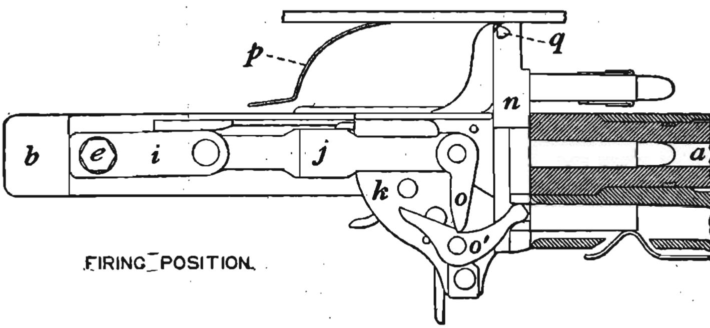


FIG. 288.

rear is stopped when the crank shaft strikes the rear edges of the slots. Fixed to the right end of the shaft is the cam lever 57. During the recoil, and after the shot has left the bore, the lower surface of the cam lever bears on the roller 58, and as the recoil continues the cam lever, riding on the roller, is rotated upward, thus producing a downward movement to the crank on the shaft between the recoil plates. The crank is seen in Fig. 287 and at *i* Figs. 288 and 289. Attached by links to the fusee, *g* Fig. 287, on the crank shaft outside the breech casing, is the operating spring *h* which at its forward end is attached to the breech casing. On recoil and rotation of the shaft the spring is extended, and at the end of the recoil the reaction of the spring returns the parts to the firing position.

324. THE BREECH MECHANISM.—The breech mechanism is

shown in Figs. 288 and 289. It consists of the lock *k* which contains the firing mechanism; the carrier *n*, a narrow piece which slides up and down the front of the lock and is provided in front with a flanged groove to engage the head of the cartridge; and the forked link *j* pivoted at its rear end to the crank *i* on the operating shaft *e*. The breech mechanism slides back and forth between the recoil plates *b* in grooves cut in the sides of the recoil plates.

The parts being in the firing position the flanged groove of the carrier *n* engages the head of a cartridge in the feed belt above the barrel and also the head of the cartridge in the barrel. When the piece is fired the barrel and breech mechanism start to the

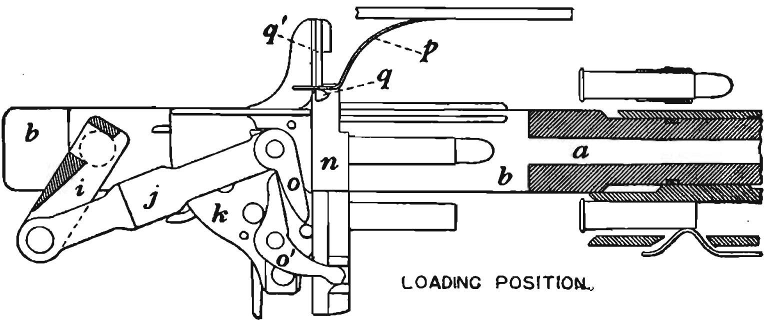


FIG. 289.

rear together. At the end of the movement of the barrel, the breech mechanism is drawn farther to the rear between the recoil plates by the rotation of the crank *i* as shown in Fig. 289.

In this movement the carrier *n* is guided by its bearings *q* which move on the upper surfaces of solid cams, 37 Fig. 286, fixed to the side plates of the breech casing. The movement of the carrier is at first straight to the rear withdrawing the cartridge from the belt and the fired shell from the chamber. The carrier is then depressed by a guide lug, 43 Fig. 86 and *p* Figs. 288 and 289, attached to the top plate of the breech casing. The loaded cartridge is thus brought opposite the barrel and the fired shell opposite the ejector tube 33. The reaction of the coiled spring now returns the parts to the firing position, the carrier *n*, Figs. 288 and 289, moving straight to the front in its depressed position. After the cartridge has been placed in the chamber, the carrier is slid upward by the action of the finger *o* against the lifting lever *o′*, the finger *o* being fixed to the link *j*. The carrier leaves the fired shell in the ejector tube where it is held by a spring to prevent its falling back into the mechanism. It is ejected from the tube by the next succeeding shell.

THE FIRING MECHANISM.—The firing mechanism, shown in Fig. 290, is contained between two plates *k*. The solid part of the forked link *j* acts in its downward movement against the projecting end of the tumbler *c*, withdrawing the firing pin until it is caught by the safety catch *e*. At the same time the sear *d* en-

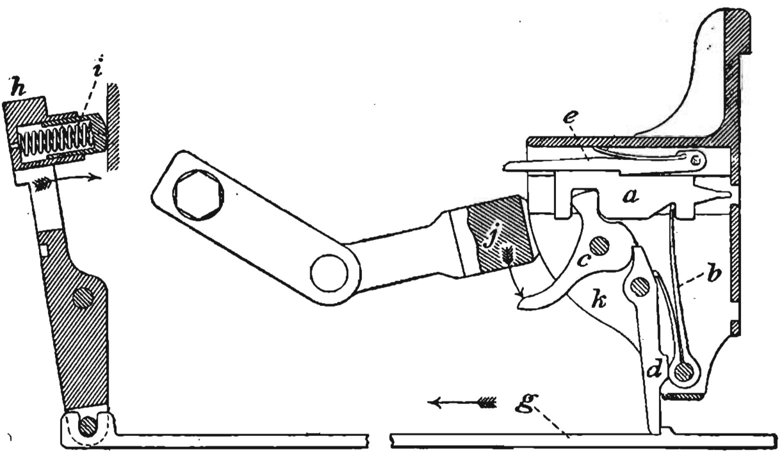


FIG. 290.

gages in the notch of the tumbler where it is held by one leaf of the spring *b*. The trigger *h* is placed at the rear outside the breech casing, between the two gun handles. A forward pressure against its upper end moves the trigger bar *g* to the rear. When the trigger is pressed the lug on the trigger bar that engages the sear *d* releases the sear from the notch in the tumbler as the breech mechanism moves forward in closing, and holds it released after the breech is closed. After the release of the sear the firing pin is held back by the safety catch *e*. The link *j* in the last part of its movement upward lifts the projecting end of the safety catch and releases the firing pin, which under the action of the spring *b* flies forward and fires the cartridge.

Page 572a
Back of Fig. 291
Faces Page 572

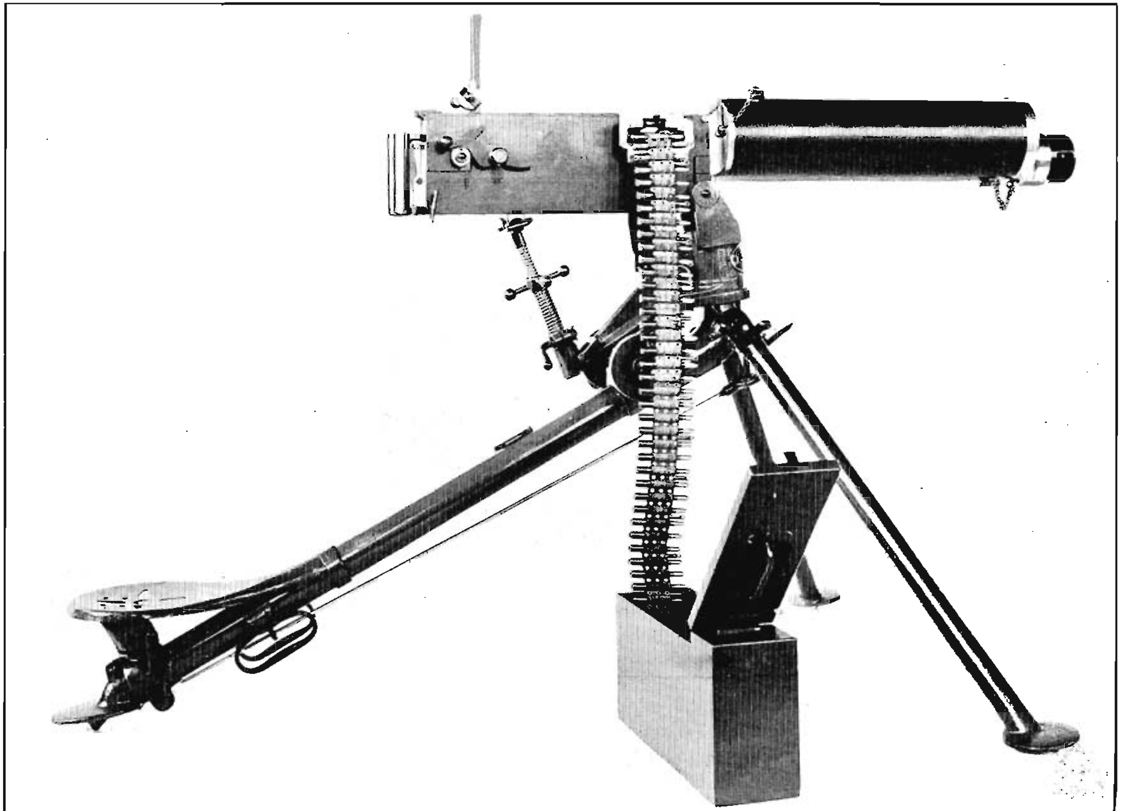


FIG. 291.—Maxim .30-Caliber Automatic Machine Gun.

The trigger is constantly pressed to the rear by the spring *i* and is provided with a safety catch to guard against accidental firing. The trigger cannot be pressed forward for firing until the safety catch is lifted.

325. The Water Jacket.—In continuous firing the barrel of an automatic rifle becomes very highly heated and if not cooled in some way may even attain a red heat. The walls of the bore are so softened by the heat that the lands of the rifling are soon worn away and the gun loses its accuracy. The accuracy is completely destroyed after about 1000 rounds fired with the water jacket empty. The necessity of cooling the barrel during firing is therefore apparent, and the gun should never be fired, except in emergency, without water in the jacket.

The water jacket of the Maxim gun holds 12 pints of water. The barrel of the gun is coated with copper on the exterior as a protection against rust. The stuffing boxes through which the barrel passes are packed with asbestos packing.

A steam tube, 89 Fig. 286, is fitted in the upper part of the water jacket to provide a means of escape for the steam that is formed in the water jacket during continuous firing. Near each end of the steam tube is a hole 89 for the admission of steam, and at the front end a hole 99 through both tube and water jacket permits escape of steam to the exterior. The steam tube is surrounded by the tubular valve 96 which slides on the steam tube and closes the forward or rear steam port according as the gun is depressed or elevated, thus preventing the entrance of water into the steam tube while permitting the entrance of steam.

The Cartridge Belt.—The cartridge belt, Fig. 291, is formed of two pieces of flax webbing connected by brass strips and eyelets between adjacent cartridges, every third strip projecting about an inch beyond the bullet edge of the belt to guide the belt properly through the feed mechanism of the gun. A flat brass handle 4 inches long is attached to each end of the belt.

Each belt holds 250 cartridges.

The cartridges are quickly and evenly inserted into the belt pockets by means of a small belt-filling machine, Fig. 292, which is attached to a bench and operated by hand.

Mounts.—For service with the infantry and cavalry the automatic gun is mounted on a tripod, Figs. 291 and 293. It is transported by means of pack animals. For transportation the legs of the tripod fold together and the rear leg telescopes. A complete outfit consists of five packs. The gun and tripod form one pack which weighs, with the equipment of the animal, 275 pounds. Each of the other four packs consists of 1500 rounds of ammunition, and accessories for the gun including water for refilling the water jacket. These packs weigh complete about 290 pounds each.

The gun with tripod, and water jacket filled with water, weighs 152 pounds. It may therefore be readily transported by hand over short distances in the field. The legs of the tripod fully extended to the front and rear form convenient shafts for carrying.

For use in fortifications the gun is mounted on a two-wheeled carriage provided with shields. The parts of the mount connecting with the gun are alike in the carriage and in the tripod mount, so that the guns may be fitted to either type of mount as desired.

Blank Firing Attachment.—The pressure produced in the discharge of a blank cartridge is not sufficient to operate the mechanism of the gun. There is therefore provided for use in drill with blank cartridges an attachment called the drill and blank firing attachment. The attachment, Fig. 293, is affixed to one of the rear gun handles and acts, through the continuous turning of a crank by hand, to operate the crank shaft of the recoil mechanism in the same manner as when operated by the explosion of a ball cartridge.

326. The Maxim One-pounder Automatic Gun.—This gun, called the *Pompom* from the noise of its explosions, is constructed on the same principles as the .30-caliber automatic gun above described.

On account of the greater size and weight of the parts and the increased total force of recoil, an additional coiled recoil spring, *s* Fig. 294, surrounds the barrel in the water jacket. The spring, as well as the barrel, is coated with copper. A small hydraulic cylinder *c* also assists in checking the recoil. The cylinder is held in the rear plate of the breech casing, the piston *p* of the cylinder being connected with a cross bar *x* held between the rear ends of the recoil plates.

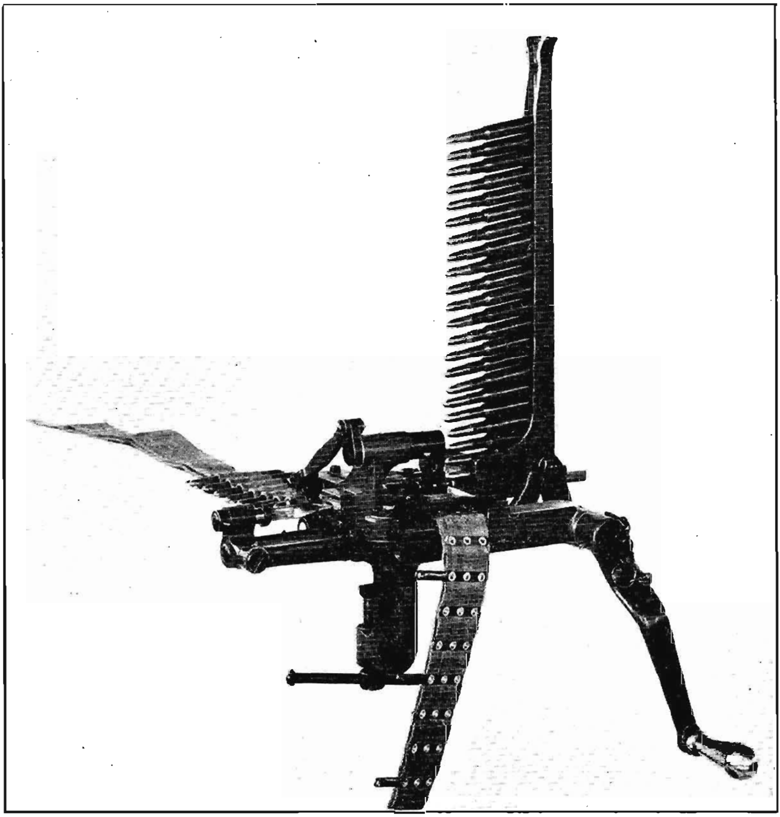


Fig. 292.—Belt Filling Machine.

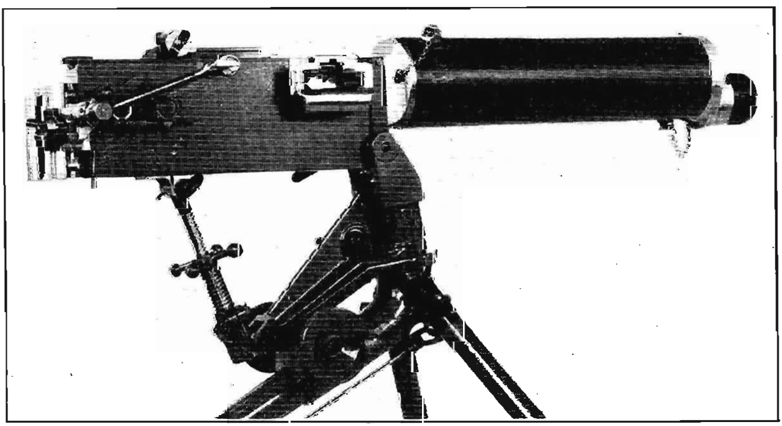


Fig. 293.—Attachment for Firing Blank Cartridges.

Maxim .30-Caliber Automatic Machine Gun.

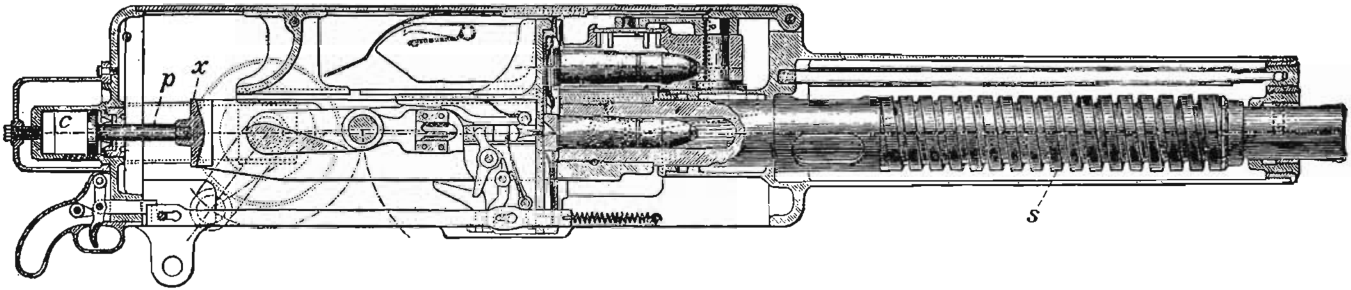


FIG. 294.—Maxim Automatic One-pounder. Pompom.

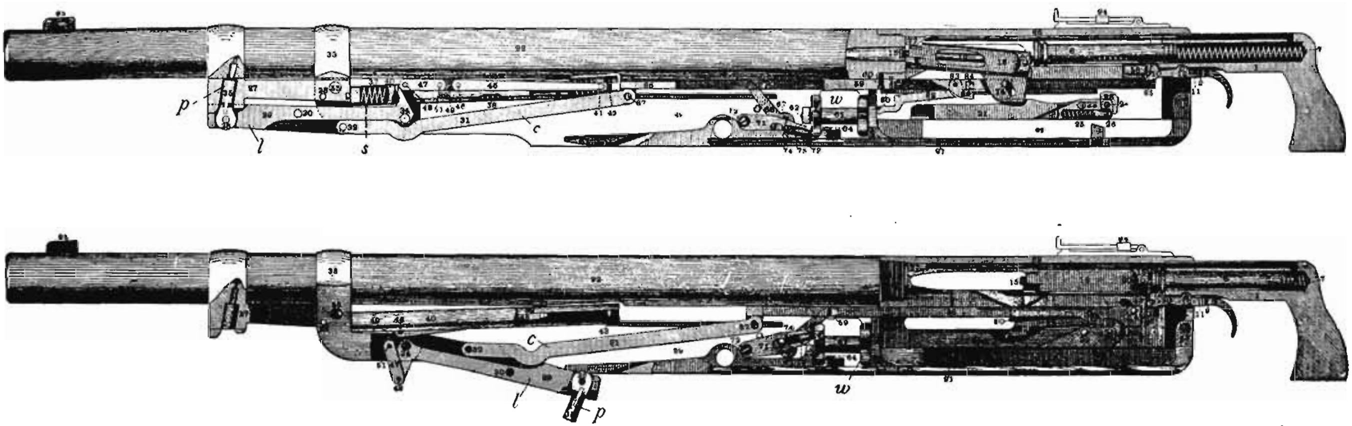


FIG. 295.—Colt .30-Caliber Automatic Machine Gun.

The caliber of the gun is 1.457 inches. It fires a shell weighing one pound, with a bursting charge of 4/10 of a pound.

The Colt Automatic Machine Gun.—The operation of the Colt automatic machine gun, Fig. 295, is effected through the direct action of the powder gases on the end of a swinging lever *l*. A vent is cut through the bottom of the stationary barrel a short distance in rear of the muzzle. When the bullet has passed the vent a portion of the powder gases enter the vent and impinge on a piston *p* attached to the lever *l*. The blow on the piston causes the lever to revolve downward and to the rear against the action of a coiled spring *s* which at the end of the movement returns the lever to its former position.

The movement of the lever is communicated by the connecting bar *c* to the mechanisms in the rear, and actuates these mechanisms to perform the successive operations necessary for the maintenance of continuous fire.

The cartridges are fed to the gun in a belt similar to that described for the Maxim gun. The feeding of the belt is accomplished by the feed wheel *w* under the rear end of the barrel.

CHAPTER XVII.

SUBMARINE MINES AND TORPEDOES. SUBMARINE TORPEDO BOATS.

327. Submarine Mines and Torpedoes.—*A submarine mine* is a charge of explosive confined in a strong case anchored in position under the surface of the water.

A torpedo is a submarine vehicle charged with explosive. The term torpedo formerly included fixed as well as moving mines, and still includes, to a certain extent, both these classes.

History.—The first recorded experiments with submarine mines were made by *David Bushnell* of Connecticut, in 1775. His mines contained charges of black powder, and explosion was effected by means of clockwork, which, after being set in motion, allowed sufficient time before the explosion for the operator to get clear.

Bushnell also constructed a submarine boat for the purpose of conveying his mines to hostile vessels. The boat, Fig. 296, was formed of two sides, each shaped like the upper shell of a tortoise. Entrance was gained through a hatch in the top. It carried but one operator, who moved the craft by means of screw propellers. The explosive was carried in a case with the firing mechanism, on the back of the boat, and was fastened by a rope to the stem of a wood screw which projected through the top of the boat. The operator was expected to bring the craft under the hostile ship, and fasten the wood screw in the ship's wooden bottom. This effected, the moving away of the submarine boat would release the mine and set the clockwork in motion, to explode the charge after a sufficient interval of time.

An attempt was actually made in 1776 with this boat against the English man-of-war *Eagle* in the harbor of New York. The operator claimed that he found the vessel, and that in attempting to fasten the screw in her bottom he struck iron. In looking for a better location he lost the vessel. He released the magazine in the harbor, and an hour afterward the explosion occurred.

Bushnell also attacked the English fleet, at Philadelphia in 1777, with drifting torpedoes. This attempt was also unsuccessful.

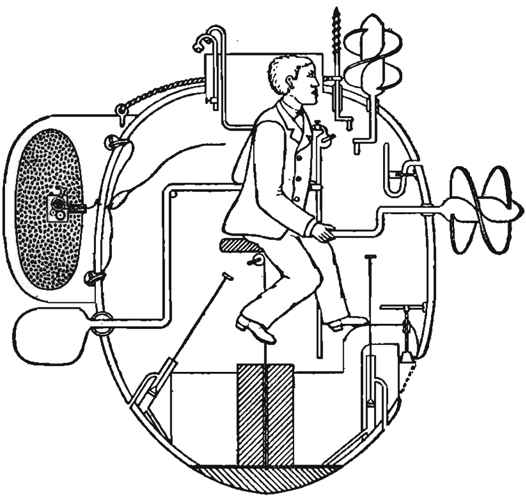


FIG. 296.

Robert Fulton experimented with torpedoes from 1797 to 1810. In 1801 he succeeded in sinking the first vessel, a small one, with a submarine mine. The mine contained 20 pounds of gunpowder. In 1804 he conducted, for the English, an unsuccessful attack with mines against the French fleet in the harbor of Boulogne. The mines exploded but did no harm to the French ships.

In 1842 *Samuel Colt* applied electricity to the firing of submarine mines, and in the following years was successful in numerous experiments in the explosion of mines at great distances from the operator.

Mines and torpedoes were first successfully used in war by the Confederates in our Civil War. With imperfect appliances they succeeded in sinking or seriously damaging more than thirty United States ships. Their success attracted the attention of the world to this method of naval attack and defense, with the result that there has followed great improvement in the appliances and methods employed, and the means for submarine warfare are now given earnest consideration by all maritime nations.

328. Confederate Mines.—The mines used by the Confederates were of various forms. The simplest and one of the most effective mines was made of a barrel, which was partially filled with black gunpowder. The charge was usually about 100 pounds. The barrel, Fig. 297, was provided with pointed ends to prevent its being overturned by the current. It was moored to float 5 or 6

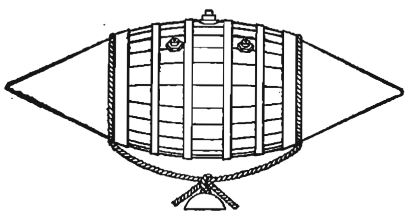


FIG. 297.

feet below the surface of the water, and a depending weight kept the top of the barrel uppermost. Screwed into sockets on top of the barrel were a number of percussion or chemical fuses. A vessel striking one of these would explode the mine.

The chemical fuse consisted of a small glass tube filled with sulphuric acid and surrounded by a mixture of chlorate of potash and white sugar, the whole enclosed in an outer lead tube. The lead tube was crushed by the blow of a striking vessel and the glass tube broken. The action of the sulphuric acid on the mixture of chlorate of potash and white sugar produced fire, which was communicated to the powder charge of the mine by a priming of black powder.

Another very effective buoyant mine, known as the Singer mine, is shown in Fig. 298. The case, made of tin, was of size sufficient to hold from 50 to 100 pounds of gunpowder, and to provide sufficient air space *a* for flotation. A percussion cap was held in a cup in the lug *e* in the midst of the powder charge, and the upper end of the rod *d* was close to the cap. A firing bolt *b* was held back against the pressure of a spiral spring by the pin *g*. A heavy iron cap *c*, connected by a wire to the pin, rested on the top of the mine. When the mine was struck the cap was knocked off. The cap in falling pulled out the pin *g*. The firing mechanism would then act and explode the mine.

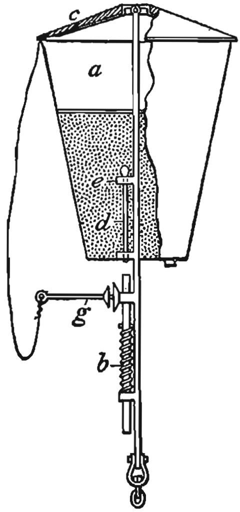


Fig. 298.

In shallow waters, frame and spar, or pile, torpedoes were used. The frame torpedo, Fig. 299, consisted of a number of inclined timbers framed together and supporting at their upper ends explosive shell provided with percussion caps.

Two forms of the spar torpedo are shown in Figs. 300 and 301. The spar torpedo was also used for offensive operations in boats. The spar, with torpedo at the end, was carried projecting from the bow of a launch.

The most noteworthy exploit with a spar torpedo was that of Lieut. W. B. Cushing, U. S. Navy, who in 1864 attacked in a launch the Confederate ironclad *Albemarle* which was tied to a dock in the river at Plymouth, N. C. The *Albemarle* was sunk by

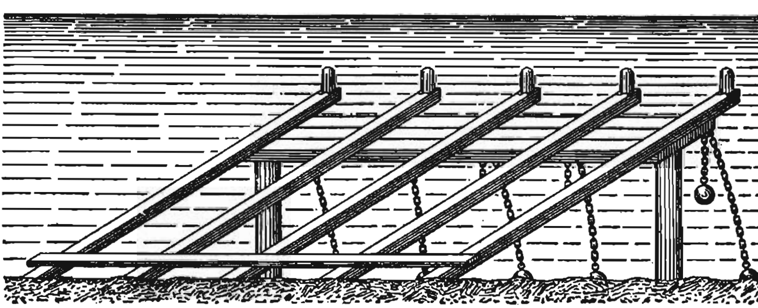


Fig. 299.

the explosion of the torpedo. So was the launch. Lieutenant Cushing and one member of his crew of thirteen escaped.

The Confederates also made use of submarine boats carrying torpedoes, and they sunk by these means the United States frigate *Housatonic* in Charleston Harbor in 1864. The submarine boat used on this occasion was worked by a crew of nine men who

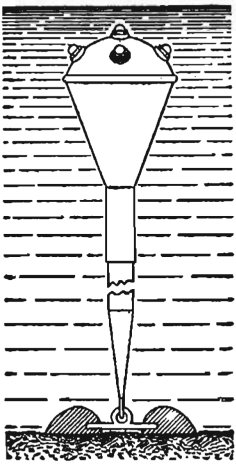


FIG. 300.

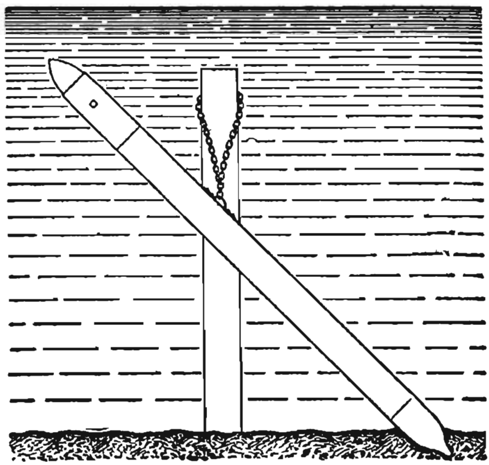


FIG. 301.

operated the propellers by hand. The boat and her crew were carried down with the *Housatonic.*

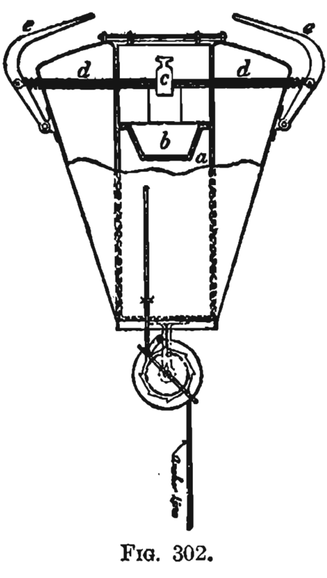


FIG. 302.

Spanish Mechanical Mine.—Fig. 302 represents a Bustamente contact mine. Seventeen of these mines were removed by our Navy from the harbor of Guantanamo, Cuba, after the capture of the harbor in 1898.

The mine is circular in cross section. It carried a charge of 100 pounds of wet guncotton in the cylinder *a* and a priming charge of dry guncotton in the chamber *b*. Against the chemical fuse *c*, a bottle containing sulphuric acid and surrounded by a mixture of chlorate of potash and sugar, rest the ends of six iron rods or plungers *d* whose outer ends are connected to the six pivoted contact arms *e*. A blow on any one of the arms *e* would cause a plunger to break the fuse. Ignition of the priming charge and explosion of the bursting charge would follow.

329. Electric Mines.—Mechanical mines such as those described above, when once planted, render the waterways dangerous to friend and foe alike. This great disadvantage is overcome in modern practice by the use of electrically controlled mines which may be made instantly operative or harmless at the will of an operator on shore.

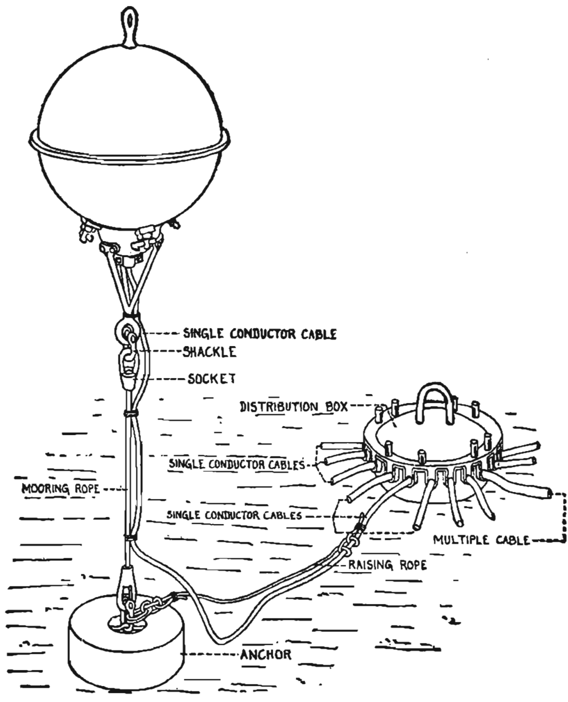


FIG. 303.

BUOYANT MINES.—A modern buoyant mine is shown in Fig. 303. The spherical case of steel contains the explosive and the circuit-closing and firing devices, with sufficient air space for flotation. A continuous insulated cable extends from the mining casemate in the fortification to the mine in position. The firing circuit is broken at the mine, and the electrical arrangements are such that the mine may be fired by the operation of the circuit-closer when the mine is struck by a vessel, or at any time at the will of the operator in the mining casemate. Or the striking of a mine may be automatically signaled to the operator, who may then fire it at once, or after a few moments delay, in order to allow a ship to get well over it, or not fire it at all.

Buoyant mines are moored at a submergence of about 5 feet at low water, so that they may be near enough to the surface to be struck by passing vessels and yet not near enough to be readily seen. They are not in general used in water less than 20 feet deep. They may be operated successfully in water 150 feet deep. In order to obtain the necessary buoyancy the mines used in waters of the greatest depths are cylindrical in shape with hemispherical ends.

GROUND MINES.—Ground mines are used when the depth of the water does not exceed 35 feet. They rest on the bottom. A heavy mushroom-shaped case contains the charge of explosive and the electric firing device. The circuit-closing device is carried by a buoyant case similar in shape to the buoyant mine. The buoy is moored, with proper submergence, to the ground mine. When the buoy is struck by a passing vessel the circuit-closer within it acts in precisely the same manner as the circuit-closer in the buoyant mine, and, if desired, completes the firing circuit that fires the charge in the mine resting on the bottom.

330. The Explosive.—Dynamite and guncotton are the principal explosives used in submarine warfare.

Dynamite has been used in the mines of the United States service. It has the advantages of cheapness and ease of ignition. Its disadvantages are danger in handling, liability to explosion when a derelict mine is struck by a vessel, and changing sensibility to the action of the detonator when freezing and thawing. If the dynamite becomes wet, through a leak in the mine case, the nitroglycerine separates from the absorbent.

Guncotton has the advantage of being perfectly safe in storage and in handling, and of detonating when wet if a small amount of dry guncotton be present. The dry cotton must be in close contact with the wet. Too much water will make the detonation uncertain. The explosive force of guncotton is less than that of dynamite.

Excellent results have recently been obtained in submarine work with the explosive *tri-nitro-toluol*.

The Charge.—Charges varying from 100 to 1000 pounds of explosive have been used in mines. A charge of 100 pounds exploded in contact with a warship's bottom will disable and probably sink the ship.

In recent experiments with a submerged target built in exact representation of the bottom of a battleship, the explosion of a 12-inch mortar shell containing 63 pounds of high explosive, at a distance of 20 feet from the target and at a depth of 15 feet, produced serious injury to the target; 64 pounds at a distance of 15 feet nearly disrupted the target and caused bad leakage, producing dangerous injury; while 130 pounds at a distance of 15 feet disrupted the double bottom and caused the target to sink immediately. The results showed the utility of this method of attack on vessels, and the desirability of using as large an explosive charge as possible in the projectiles for the seacoast mortars.

General Henry L. Abbott, Corps of Engineers, U. S. Army, conducted a very extensive series of subaqueous experiments with different explosives. He deduced the following formulas for the energy and pressure delivered at a distance by a subaqueous explosion.

$$W=\frac{58C}{(D+0.01)^{2\cdot 1}}$$

$$P=\left(\frac{1,832,000C}{(D+0.01)^{2\cdot 1}}\right)^{\frac{2}{3}}$$

in which W represents the energy per square inch,
P the pressure in pounds per square inch,
C the weight of charge, in pounds,
D the distance in feet.

Applying the pressure formula to the explosions of the three mortar shell in the vicinity of the battleship target, we find that the pressures on the target were, in order, 3574, 5401, and 8662 pounds per square inch.

331. Defensive Mine Systems.—The submarine mine system is used as an auxiliary in the defense of a river or harbor in connection with the land fortifications, and its chief purpose is to so limit and obstruct the approach of the enemy's vessels that they will be compelled to make frontal attack on the fortifications and be held exposed to the fire of the heaviest guns.

In order that the most effective fire may be employed the outer lines of mines are planted at a distance from the fortifications, not exceeding the most effective range of the guns.

The usual mine system for the defense of a harbor is illustrated in Fig. 304. Concealed and protected in a fortification is the

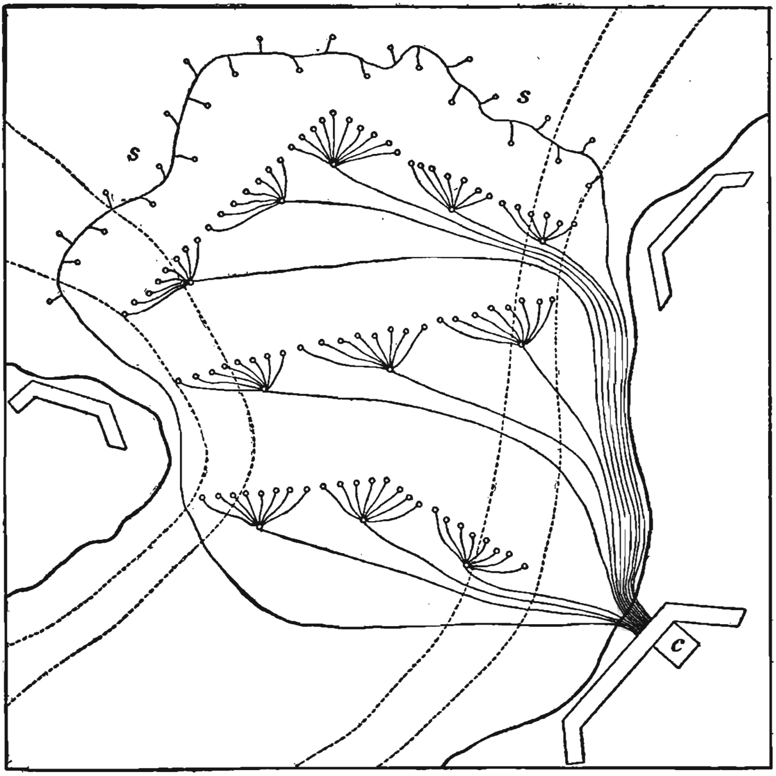


FIG. 304.

mining casemate *C* which contains the electric generators, batteries, and instruments needed in the service of the mines. From this point the mines are controlled.

The mines are planted, in the waterways to be defended, in groups, for convenience of service.

Multiple conductor cables, one for each group, lead from the mining casemate to junction or distribution boxes similar to that shown in Fig. 303. In the junction box the conductors of the multiple cable are separated and joined to the conductors of single conductor cables which lead to the individual mines of the group. Thus each mine has its own cable and may be operated independently of all the other mines.

The course of a hostile vessel approaching or moving through the mine fields is observed by means of the range and position finding system of the fortification, and the operator in the mining casemate is apprised of the proximity of the vessel to any mine.

In addition to the groups of mines, other mines, called skirmish mines, *s* Fig. 304, may be laid on single cables in irregular lines about the groups. The skirmish mines may be made active or safe at the will of the operator, but cannot, on account of their arrangement on a single cable, be fired singly by judgment.

The arrangement of all the mines is such that a vessel can follow no reasonable course into the harbor without encountering several mines. Gaps, left between the groups in the various lines, form a more or less tortuous channel which allows passage to friendly vessels. Guide boats are employed to conduct friendly vessels through the safe passages.

Subsidiary waterways not of service to the defense may be closed to the enemy by mechanical mines, which contain within themselves the electric batteries that provide the firing current.

In the fortifications, gun batteries, usually of 3-inch guns, cover the mine fields, and protect them against attempts of the enemy to clear the fields by countermining from boats.

Search lights are provided to illuminate the mine fields at night.

332. **Countermining.**—Countermining consists in exploding and cutting adrift the fixed mines of the enemy and destroying their cable connections by the explosion of other mines distributed among them. The purpose of countermining is to make a safe channel through the mines of the defense. Countermining is usually done at night from small boats.

The Removal of Mines.—The experience had in clearing the harbors of the United States of mines after the Spanish War indicates that the safest way to remove the mines is to explode them in place.

Mobile and Automobile Torpedoes.—The mobile torpedo conveys the explosive charge under the water and explodes the charge against the bottom of the enemy's ship. Mobile torpedoes are now used exclusively by navies, and all such torpedoes are self-propelling or automobile. The necessity of erecting on shore, at the water's edge, special plants for the service of the torpedoes, and the necessity of protecting such plants, are considerations that militate against the use of mobile torpedoes for harbor defense.

The Sims-Edison Torpedo.—A long series of experiments were made a number of years ago with the Sims-Edison torpedo, Fig. 305, to determine whether this torpedo was adapted for harbor defense.

The torpedo consists of a cylindrical hull with conical ends. It is 28 feet long, 21 inches in diameter, and is supported at a depth

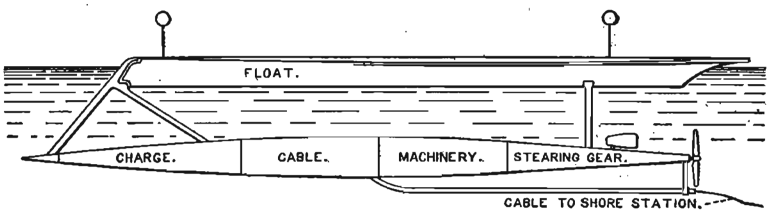


FIG. 305.

of 5 feet under the water by a float, to which it is connected by steel rods. Two balls carried above the float enable the operator on shore to observe the position of the torpedo and to direct its movement. The torpedo is propelled, steered, and exploded by electricity. The power is generated at a station on shore and is communicated to the torpedo through a cable which is carried coiled in a central chamber and is paid out as the torpedo moves.

A charge of 300 pounds of explosive is carried in the head of the torpedo.

The results obtained in the experiments were not sufficiently satisfactory to warrant the adoption of this torpedo for the harbor defense service.

333. **The Whitehead Torpedo.**—The Whitehead torpedo, Fig. 306, is now used by all the navies of the world. Its motive power is furnished by compressed air which is stored, at a pressure of about 1100 pounds per square inch, in a tank carried by the torpedo.

The torpedo is fired, by compressed air or by gunpowder, from launching tubes that are mounted on the ship's deck or built into the ship below the water line. A torpedo tube arranged for firing with compressed air is shown mounted on the deck of a torpedo boat, in Fig. 307.

The explosive charge, carried in the head of the torpedo, is fired by percussion when the torpedo strikes.

SUBMERSION MECHANISM.—In a chamber in rear of the air tank is the mechanism for regulating the depth of the torpedo. The head of a piston, acted on by springs, protrudes through a central hole in the rear wall of the chamber into another narrow chamber to which the water has access through the holes in the walls of the torpedo. The water pressure thus acts on one side of the piston

FIG. 306.

and the springs on the other. The springs may be regulated to exert a pressure on the piston equal to the pressure of the water at any desired depth. At that depth the piston will be stationary, while at any other depth it will be moved forward or backward. The piston is connected with horizontal diving rudders at the tail of the torpedo, one on each side. Any movement of the piston caused by the departure of the torpedo from the depth for which it is adjusted is communicated to these rudders, which act to return the torpedo to the desired depth.

The piston ceases to act when the torpedo is at the fixed depth, whatever may be the position of the longitudinal axis of the torpedo. As the axis will not be horizontal when the depth is reached the torpedo, if controlled by the piston alone, will overrun the depth and then return again to it, and will continue in this way rising and descending. To prevent this action a heavy pendulum, in the chamber with the piston, is also connected with the diving rudders. The pendulum remains vertical, and at any departure of the axis of the torpedo from the horizontal, the diving rudders are turned to correct the departure. The piston and pendulum together thus serve to keep the torpedo on an even keel at the desired submergence.

THE MOTIVE ENGINES.—The motive engines in the next compartment are supplied with compressed air through pipes that lead from the tank forward. The engines actuate two shafts, one within the other, that carry the propellers. The propellers turn in opposite directions. This arrangement of the propellers serves better than any other arrangement to prevent rolling of the torpedo.

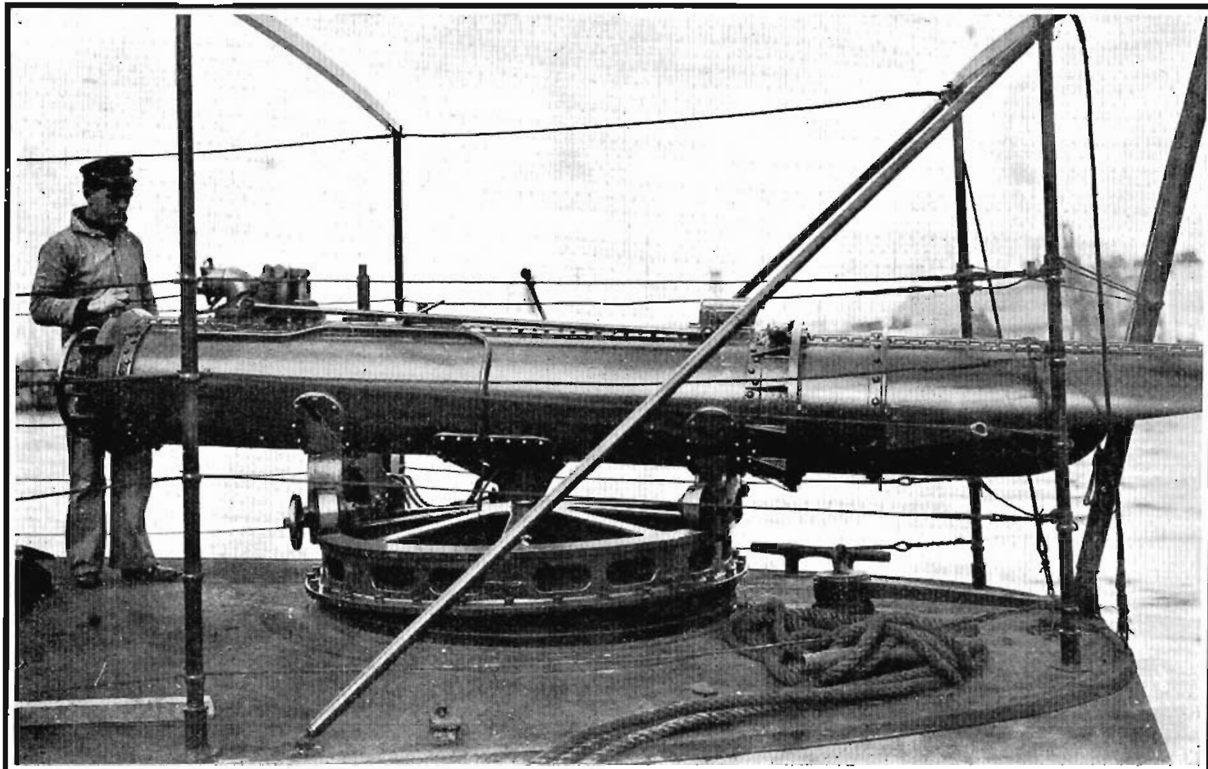
DIRECTING MECHANISM.—The compartment in rear of the engine contains the device for correcting any deviation of the torpedo from a straight course. A small gyroscope, with wheel about 3 inches in diameter, is mounted under the propeller shaft with its axis parallel to the axis of the torpedo. The gyroscope is set in motion by a spring-actuated mechanism at the launching of the torpedo. The axis of the gyroscope tends always to remain parallel to its original direction, and at any departure of the axis of the torpedo from its original direction the gyroscope actuates the valve of a small air steering-engine which moves the vertical rudders of the torpedo in such manner as to bring the torpedo back to its course.

SINKING MECHANISM.—In order to sink the torpedo at the end of its course, if it does not strike its target, and thus to prevent its falling into the hands of the enemy or doing injury to friends, a mechanism is provided which opens a sea-valve into the comparatively empty chamber that contains the gyroscope. The water fills the chamber and sinks the torpedo.

DATA.—The Whitehead torpedo has a diameter of 18 inches, and a length of about 16 feet. It has a mean velocity of 28 knots an hour over a range of 2200 yards. The charge of explosive weighs 60 pounds.

The Schwarzkopf torpedo differs from the Whitehead only in that the body of the torpedo is made of bronze instead of steel.

334. **The Bliss-Leavitt Torpedo.**—The Bliss-Leavitt torpedo, a recent American construction, and in use in the United States Navy, is of the same general construction as the Whitehead torpedo. Improvements in the mechanisms give to this torpedo greater range and greater accuracy.



Courtesy of the SCIENTIFIC AMERICAN.

FIG. 307.—Torpedo in Tube, Ready for Launching.

Page 588b
Back of Fig. 307
Faces Page 589

The air tank is charged to a pressure of 2225 pounds per square inch. The motor engine is of the Curtis turbine type and makes 10,000 revolutions a minute, operating the two propellers at the rate of 900 turns a minute. A large gain in power is obtained by a superheating process applied to the compressed air. An alcohol flame, automatically ignited when the torpedo is launched, greatly increases the expansive power of the compressed air as it enters the engine. The expansion is so great that trouble has been encountered from the freezing of the mechanism. Temperatures of 40° below zero have been registered in some runs.

The gyroscope controlling the vertical rudders is also of a turbine construction, and is rotated by compressed air at the rate of 18,000 revolutions a minute. It is much more effective in maintaining the torpedo in a fixed course than the spring-actuated gyroscope in the Whitehead torpedo. The accuracy of the torpedo is therefore greatly increased.

The Bliss-Leavitt torpedo is made in two sizes, 18 and 21 inches in diameter. The 21-inch torpedo is about 16½ feet long. It has an extreme range of 3500 yards and a mean speed over that range of 28 knots an hour. Over a range of 1200 yards its mean speed is 36 knots.

The explosive charge consists of 132 pounds of wet guncotton containing 25 per cent of water.

The firing mechanism in the point is the same as in the Howell torpedo described below.

The Howell Torpedo.—The Howell torpedo was invented by Admiral John A. Howell, United States Navy. The motive power of the Howell torpedo is a solid flywheel, *w* Fig. 308, which is

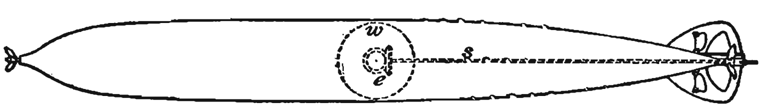


FIG. 308.

caused to revolve at a rate of 10,000 revolutions a minute, before the torpedo is launched, by a small turbine engine located in the launching tube. The rotation of the flywheel is communicated to two propellers, one on each side, through the bevel gears *e* and shafts *s*.

A device applied to the propellers increases the pitch of the blades as their velocity of rotation diminishes, thus better maintaining the speed of the torpedo at the latter end of its course.

The gyroscopic power of the rotating flywheel gives to the torpedo great rigidity of direction in the horizontal plane.

The submergence is regulated by a hydrostatic piston and pendulum that act on the horizontal rudders at the tail, the mechanism being similar to that described in the Whitehead torpedo.

The small screw at the nose of the torpedo locks the firing mechanism in the safety position until the torpedo has traveled 30 or 40 yards through the water. The rotation of the screw during this travel arms the firing mechanism.

The Howell torpedo carried a charge of 174 pounds of guncotton. It was fired by gunpowder from the launching tube. Its extreme effective range, 1000 yards, was so limited that the torpedo never came into general use.

Towing Torpedoes.—Towing torpedoes are so arranged that they may be made to diverge to a considerable extent on either side of the wake of the towing vessel, so that this vessel may pass clear of the ship attacked and yet cause the torpedo to strike. Towing torpedoes were used by the Russians in their war with Turkey, 1877, but in no case with success.

335. Submarine Torpedo Boats.—While submarine torpedo boats are now used only by the navy, it has been recommended that they be used by the Coast Artillery as adjuncts to the submarine mine systems. They will perform a twofold function in the mine fields: first, in the inspection and repair of the mines and cables and other subaqueous material, to which access will be gained through a diving compartment or caisson provided in the boat; and second, in supplementing the fixed mines by defending with the torpedo those channels or passages that by reason of the great depth or the strength of the current cannot be closed by fixed mines.

Submarine boats are of two general classes, the *diving* boat and the *submersible* boat. The diving boat submerges by inclination of its longitudinal axis effected through horizontal rudders. It rises by the same means. The submersible boat sinks and rises

Page 590a
Back of Fig. 309
Faces Page 590

Fig. 309.—Holland Submarine Torpedo Boat.

bodily with even keel, the movements being effected by the vertical component of the water pressure against inclined hydroplanes projecting from both sides of the boat and symmetrically disposed with respect to the center of gravity.

Both classes of boats are provided with gasoline engines for propulsion on the surface, and with electric motors for use when submerged. When on the surface the motors may be used as dynamos to charge the storage batteries, the power being supplied by the gasoline engines.

To adjust the buoyancy, water is pumped into or out of the ballast tanks by pumps actuated by the engines or motors.

Air compressors and tanks are also provided. The compressed air is used for the discharge of the torpedoes, and to supplement the pumps in the discharge of water ballast.

The compressed air may also be used to renew the air supply in the vessel when submerged. The renewal of the air supply is, however, usually not necessary. Tests have shown that the crew does not suffer from bad air when the boat is hermetically sealed for long periods. In one test 7 men remained under water for 15 hours without change of air and without discomfort. In another test the boat, fully manned, remained totally submerged for 12 hours without change of air. In a recent test the boat, with 13 men aboard, remained submerged at a depth of about 40 feet for a period of 24 hours. During the last hours air was drawn from the compressed air supply. The test showed that the boat could remain under water for three days before exhausting the supply of air.

The Holland Submarine Boat.—The Holland submarine boat is the latest and most successful boat of the diving type of submarine.

The boat, Fig. 309, is spindle-shaped, circular in cross-section, with its greatest diameter about one third of its length from the bow. The single propeller is actuated by gasoline engines when the boat is on the surface, and by electric engines when the boat is awash or submerged.

Submergence is effected by means of horizontal diving rudders at the tail, arranged similarly to the diving rudders of the Whitehead torpedo.

The internal arrangements of the craft do not differ materially from those of the Lake submarine boat illustrated in Fig. 311, except that the Holland boat contains no diving caisson. The conning tower projects very slightly above the general outline of the boat.

At a recent government test of the Holland boat *Octopus* an average speed of 11 knots an hour was maintained by the boat in cruising condition on the surface, and 10 knots an hour when awash and submerged.

336. The Lake Submarine Boat.—The Lake submarine boat is of the *submersible* type. An exterior view of the *Protector*, the first torpedo boat of this type, is shown in Fig. 310, and an interior view of the boat submerged is shown in Fig. 311.

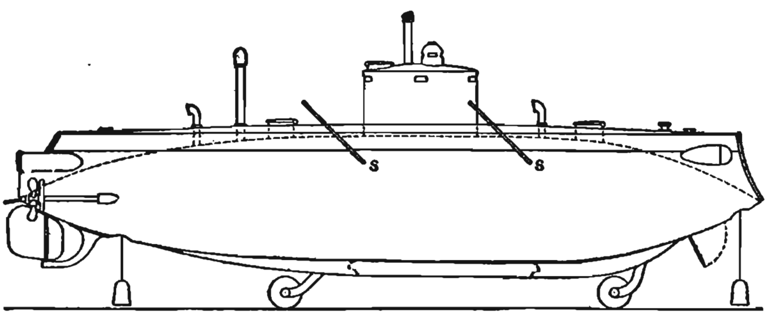
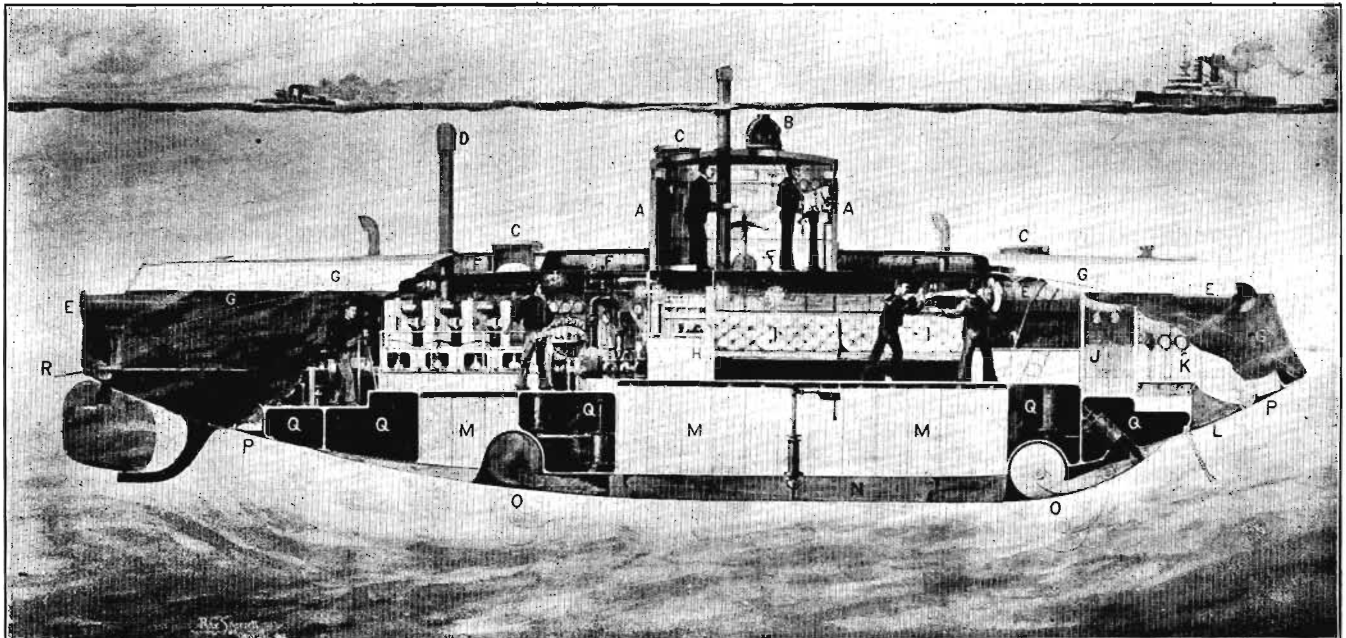


FIG. 310.

The hull is spindle-shaped, 67½ feet long with 14 feet beam. The draught, in cruising condition on the surface, is 12 feet. The displacement is 136 tons in cruising trim and 175 tons when submerged. A superstructure is erected on the hull, the top of the superstructure forming the deck of the boat. The space between the superstructure and the hull is occupied by the air, oil, and ballast tanks, and by the tanks for the gasoline used in the engines. The storage of the gasoline outside the hull greatly diminishes the chances of explosion from leaking gasoline, or of the asphyxiation of the crew from the same cause.

A conning tower rises from the hull. A sighting hood projects above the conning tower, and the omniscope, through which vision is obtained in all directions, rises 3 or 4 feet above the sighting hood.



A, A, Bronze Conning Tower.	F, F, Gasoline Tanks.	K, Diving Compartment.	O, O, Wheels.
B, Sighting Hood.	G, G, Line of Spindle Hull.	L, Diving Door.	P, P, Anchor Weights.
C, C, Hatches.	H, Galley Compartment.	M, M, Storage Batteries.	Q, Q, Ballast Tanks.
D, Exhaust from Engines.	I, I, Crew Space.	N, N, Drop Keel.	R, Horizontal Rudder.
E, E, Torpedo Tubes.	J, Air Lock.		

FIG. 311.—Lake Submarine Torpedo Boat.

Page 592b
Back of Fig. 311
Faces Page 593

The boat is built to withstand an exterior pressure of 75 pounds to the square inch, which corresponds to a depth of about 150 feet.

The boat is provided with twin screws.

SUBMERSION.—Submergence is effected on an even keel; when under way, by inclining the four hydroplanes, *s* Fig. 310, downward and forward; and when the boat is stationary by dropping the anchors at each end, reducing the buoyancy to less than the combined weight of the anchors, and then pulling the boat downward by the anchor chains. All these operations are simply effected from the conning tower.

The horizontal rudder, *R* Fig. 311, is used only to counteract the pressure of the water on the front of the conning tower when the boat is running submerged.

The buoyancy of the boat is increased or diminished by pumping water out of or into the ballast tanks. A reserve of about 300 pounds of buoyancy is always maintained except when running on the bottom, and the boat is held submerged either by the anchors or, when moving, by the water pressure on the hydroplanes. It may be kept at any desired submergence, whether moving or at rest.

For running on the bottom, wheels are provided which are ordinarily carried in pockets in the keel and which are brought into position under the keel by hydraulic mechanism. The wheels are simple rollers and the propellers move the boat, the chief function of the wheels being to protect the bottom of the boat against injury from obstacles on the bottom.

When the buoyancy has been destroyed and when, through any accident to the pumps, it cannot be regained by discharging ballast, two sections of the keel, *N* Fig. 311, weighing together 5 tons, may be dropped from the boat by the turn of a wrench. Should this not be sufficient to cause the boat to rise, the two anchors, weighing half a ton each, may be let go. As a last resource the crew may escape through the diving chamber.

THE DIVING CHAMBER.—The diving chamber in the forward compartment is a feature of this boat that makes the boat especially valuable for submarine mine work. An air lock affords access to the chamber from the interior, and a downwardly-opening watertight door in the hull affords egress to the bottom. The diving chamber has telephonic communication with the conning tower.

ARMAMENT AND SPEED.—The boat carries three torpedoes, two in the tubes in the bow and one in the stern tube. The torpedoes are discharged from the tubes by compressed air. Extra torpedoes may be carried in the living room.

The first boat of this type made, in the official trials by the Russian Government, a speed of 9.3 knots an hour on the surface, under engines and motors combined, and 8.5 knots under engines alone. With conning tower awash and under engines alone the speed was 7.4 knots; and totally submerged, under electric motors alone, the speed was 5.4 knots. The cruising radius on the surface at full speed is about 350 knots. The submerged cruising radius, with motors, is about 20 knots at full speed and 30 knots at economical speed.

A Lake boat, with a displacement of 235 tons, is now (May, 1907) undergoing test by the United States Government, and boats with 500 tons displacement are projected.

TABLES.

TABLE I.

LOGARITHMS OF THE X FUNCTIONS.

Subtract 10 from each characteristic greater than 2.

x	$\log X_0$	$\log X_1$	$\log X_2$	$\log X_3$	$\log X_4$	$\log X_5$
0.001	9.03899	5.56162	6.52263	8.73764	9.16405	8.30001
0.010	9.53911	7.05911	7.52000	9.23296	9.66437	9.30059
0.05	9.88671	8.09440	8.20769	9.56059	0.01322	9.99778
0.10	0.03494	8.53009	8.49515	9.68493	0.16295	0.29663
0.15	0.12078	8.77897	8.65819	9.74798	0.25023	0.47060
0.20	0.18111	8.95170	8.77059	9.78653	0.31194	0.59347
0.25	0.22750	9.08291	8.88541	9.81206	0.35965	0.68834
0.30	0.26509	9.18802	8.92293	9.82962	0.39851	0.76552
0.35	0.29661	9.27522	8.97861	9.84191	0.43127	0.83052
0.40	0.32372	9.34942	9.02570	9.85051	0.45956	0.88660
0.45	0.34746	9.41375	9.06630	9.85640	0.48444	0.93587
0.50	0.36855	9.47036	9.10181	9.86028	0.50663	0.97980
0.55	0.38750	9.52077	9.13327	9.86260	0.52665	1.01937
0.60	0.40469	9.56610	9.16141	9.86371	0.54488	1.05539
0.65	0.42041	9.60719	9.18678	9.86386	0.56161	1.08840
0.70	0.43489	9.64471	9.20982	9.86325	0.57705	1.11887
0.75	0.44829	9.67918	9.23089	9.86201	0.59140	1.14715
0.80	0.46075	9.71100	9.25025	9.86027	0.60479	1.17352
0.85	0.47241	9.74052	9.26812	9.85811	0.61733	1.19821
0.90	0.48334	9.76802	9.28468	9.85562	0.62913	1.22143
0.95	0.49363	9.79373	9.30010	9.85284	0.64027	1.24332
1.00	0.50334	9.81784	9.31450	9.84984	0.65081	1.26404
1.05	0.51255	9.84053	9.32798	9.84664	0.66082	1.28369
1.10	0.52128	9.86193	9.34065	9.84329	0.67034	1.30239
1.15	0.52960	9.88217	9.35258	9.83981	0.67942	1.32020
1.20	0.53752	9.90136	9.36384	9.83623	0.68809	1.33721
1.25	0.54508	9.91958	9.37449	9.83256	0.69640	1.35348
1.30	0.55234	9.93693	9.38459	9.82882	0.70436	1.36908
1.35	0.55929	9.95346	9.39417	9.82503	0.71201	1.38406
1.40	0.56597	9.96926	9.40329	9.82119	0.71936	1.39846
1.45	0.57238	9.98436	9.41198	9.81732	0.72644	1.41230
1.50	0.57856	9.99884	9.42028	9.81343	0.73328	1.42569
1.55	0.58452	0.01272	9.42820	9.80953	0.73988	1.43858
1.60	0.59026	0.02605	9.43579	9.80561	0.74625	1.45104
1.65	0.59582	0.03887	9.44305	9.80169	0.75242	1.46310
1.70	0.60119	0.05122	9.45003	9.79777	0.75840	1.47478
1.75	0.60639	0.06311	9.45672	9.79386	0.76419	1.48608
1.80	0.61143	0.07459	9.46316	9.78996	0.76981	1.49705
1.85	0.61632	0.08567	9.46935	9.78607	0.77527	1.50770
1.90	0.62106	0.09638	9.47532	9.78219	0.78057	1.51803
1.95	0.62567	0.10675	9.48108	9.77833	0.78573	1.52808
2.0	0.63015	0.11678	9.48663	9.77449	0.79075	1.53788
2.1	0.63875	0.13591	9.49717	9.76687	0.80040	1.55668
2.2	0.64691	0.15395	9.50704	9.75939	0.80958	1.57456
2.3	0.65467	0.17097	9.51630	9.75193	0.81833	1.59158
2.4	0.66207	0.18708	9.52501	9.74461	0.82668	1.60783

LOGARITHMS OF THE X FUNCTIONS—*Continued.*

Subtract 10 from each characteristic greater than 2.

x	log X_0	log X_1	log X_2	log X_3	log X_4	log X_5
2.5	0.66914	0.20236	9.53322	9.73740	0.83467	1.62338
2.6	0.67589	0.21687	9.54098	9.73031	0.84232	1.63824
2.7	0.68237	0.23070	9.54833	9.72333	0.84966	1.65250
2.8	0.68859	0.24389	9.55531	9.71645	0.85673	1.66623
2.9	0.69457	0.25650	9.56194	9.70969	0.86353	1.67945
3.0	0.70032	0.26858	9.56826	9.70304	0.87009	1.69216
3.1	0.70587	0.28014	9.57427	9.69650	0.87642	1.70442
3.2	0.71122	0.29124	9.58001	9.69007	0.88252	1.71627
3.3	0.71639	0.30190	9.58551	9.68374	0.88842	1.72773
3.4	0.72140	0.31217	9.59077	9.67752	0.89416	1.73882
3.5	0.72624	0.32205	9.59582	9.67140	0.89970	1.74956
3.6	0.73093	0.33159	9.60066	9.66538	0.90508	1.75997
3.7	0.73548	0.34079	9.60532	9.65946	0.91027	1.77004
3.8	0.73990	0.34969	9.60979	9.65363	0.91537	1.77989
3.9	0.74419	0.35829	9.61410	9.64790	0.92037	1.78955
4.0	0.74836	0.36662	9.61825	9.64225	0.92510	1.79872
4.2	0.75637	0.38250	9.62613	9.63122	0.93432	1.81656
4.4	0.76398	0.39745	9.63348	9.62053	0.94308	1.83349
4.6	0.77121	0.41157	9.64036	9.61015	0.95143	1.84962
4.8	0.77810	0.42492	9.64682	9.60008	0.95939	1.86500
5.0	0.78469	0.43759	9.65290	9.59029	0.96700	1.87971
5.2	0.79099	0.44963	9.65864	9.58079	0.97430	1.89379
5.4	0.79703	0.46110	9.66407	9.57153	0.98130	1.90730
5.6	0.80284	0.47205	9.66921	9.56252	0.98803	1.92028
5.8	0.80842	0.48251	9.67409	9.55375	0.99450	1.93277
6.0	0.81379	0.49253	9.67874	9.54521	1.00074	1.94479
6.2	0.81897	0.50213	9.68316	9.53687	1.00676	1.95640
6.4	0.82397	0.51136	9.68738	9.52874	1.01257	1.96760
6.6	0.82881	0.52022	9.69142	9.52081	1.01819	1.97844
6.8	0.83349	0.52875	9.69528	9.51306	1.02363	1.98891
7.0	0.83801	0.53698	9.69897	9.50549	1.02890	1.99905
7.2	0.84241	0.54492	9.70252	9.49809	1.03402	2.00892
7.4	0.84667	0.55259	9.70592	9.49085	1.03898	2.01847
7.6	0.85081	0.56000	9.70919	9.48377	1.04379	2.02776
7.8	0.85483	0.56717	9.71234	9.47683	1.04848	2.03677
8.0	0.85873	0.57411	9.71538	9.47004	1.05304	2.04552
8.2	0.86254	0.58084	9.71830	9.46341	1.05748	2.05408
8.4	0.86625	0.58737	9.72112	9.45689	1.06180	2.06240
8.6	0.86986	0.59371	9.72385	9.45050	1.06601	2.07050
8.8	0.87338	0.59986	9.72648	9.44424	1.07012	2.07841
9.0	0.87682	0.60585	9.72903	9.43809	1.07413	2.08612
9.2	0.88017	0.61167	9.73150	9.43206	1.07804	2.09345
9.4	0.88345	0.61734	9.73390	9.42614	1.08187	2.10100
9.6	0.88665	0.62286	9.73621	9.42033	1.08560	2.10819
9.8	0.88978	0.62824	9.73846	9.41462	1.08926	2.11502
10.0	0.89284	0.63349	9.74065	9.40901	1.09283	2.12209
10.2	0.89584	0.63860	9.74276	9.40349	1.09633	2.12882
10.4	0.89877	0.64360	9.74482	9.39807	1.09976	2.13540
10.6	0.90165	0.64848	9.74683	9.39274	1.10312	2.14186
10.8	0.90447	0.65324	9.74877	9.38749	1.10640	2.14818

LOGARITHMS OF THE X FUNCTIONS—*Continued.*

Subtract 10 from each characteristic greater than 2.

x	log X_0	log X_1	log X_2	log X_3	log X_4	log X_5
11.0	0.90723	0.65790	9.75067	9.38233	1.10963	2.15437
11.2	0.90993	0.66245	9.75252	9.37725	1.11279	2.16045
11.4	0.91259	0.66691	9.75432	9.37225	1.11589	2.16642
11.6	0.91520	0.67127	9.75607	9.36732	1.11893	2.17227
11.8	0.91776	0.67554	9.75778	9.36247	1.12192	2.17801
12.0	0.92027	0.67972	9.75945	9.35770	1.12485	2.18364
12.2	0.92274	0.68381	9.76108	9.35301	1.12772	2.18916
12.4	0.92516	0.68783	9.76267	9.34836	1.13057	2.19462
12.6	0.92754	0.69176	9.76422	9.34379	1.13335	2.19996
12.8	0.92989	0.69562	9.76574	9.33928	1.13609	2.20522
13.0	0.93219	0.69941	9.76722	9.33484	1.13877	2.21039
13.2	0.93446	0.70313	9.76867	9.33045	1.14142	2.21547
13.4	0.93669	0.70678	9.77009	9.32613	1.14402	2.22047
13.6	0.93888	0.71036	9.77148	9.32186	1.14659	2.22539
13.8	0.94104	0.71388	9.77284	9.31766	1.14911	2.23023
14.0	0.94317	0.71734	9.77417	9.31350	1.15159	2.23400
14.2	0.94527	0.72074	9.77547	9.30940	1.15403	2.23970
14.4	0.94733	0.72408	9.77675	9.30535	1.15644	2.24433
14.6	0.94936	0.72736	9.77800	9.30136	1.15882	2.24888
14.8	0.95137	0.73059	9.77922	9.29741	1.16115	2.25337
15.0	0.95334	0.73377	9.78043	9.29351	1.16346	2.25780
15.2	0.95529	0.73689	9.78160	9.28966	1.16573	2.26216
15.4	0.95721	0.73997	9.78276	9.28585	1.16797	2.26647
15.6	0.95910	0.74301	9.78391	9.28208	1.17018	2.27073
15.8	0.96097	0.74599	9.78501	9.27837	1.17236	2.27495
16.0	0.96282	0.74892	9.78610	9.27470	1.17450	2.27912
16.2	0.96463	0.75181	9.78718	9.27107	1.17663	2.28309
16.4	0.96643	0.75466	9.78823	9.26748	1.17872	2.28711
16.6	0.96820	0.75747	9.78927	9.26393	1.18078	2.29108
16.8	0.96995	0.76024	9.79029	9.26042	1.18282	2.29500
17.0	0.97168	0.76297	9.79129	9.25695	1.18483	2.29886
17.2	0.97338	0.76566	9.79227	9.25352	1.18682	2.30268
17.4	0.97507	0.76831	9.79324	9.25012	1.18879	2.30645
17.6	0.97673	0.77093	9.79419	9.24676	1.19072	2.31017
17.8	0.97838	0.77351	9.79513	9.24344	1.19264	2.31385
18.0	0.98001	0.77606	9.79605	9.24015	1.19454	2.31750
18.2	0.98161	0.77856	9.79696	9.23689	1.19640	2.32108
18.4	0.98320	0.78104	9.79785	9.23367	1.19825	2.32463
18.6	0.98477	0.78349	9.79872	9.23048	1.20008	2.32814
18.8	0.98632	0.78591	9.79959	9.22732	1.20188	2.33161
19.0	0.98785	0.78829	9.80044	9.22419	1.20367	2.33504
19.2	0.98937	0.79065	9.80128	9.22109	1.20543	2.33843
19.4	0.99086	0.79296	9.80210	9.21803	1.20717	2.34177
19.6	0.99235	0.79527	9.80292	9.21499	1.20891	2.34510
19.8	0.99382	0.79754	9.80372	9.21198	1.21062	2.34838
20.0	0.99527	0.79978	9.80451	9.20900	1.21230	2.35162

Table II.

HEATS OF FORMATION, AT 15° C. AND NORMAL ATMOSPHERIC PRESSURE (760 MM). LARGE CALORIES.

Name.	Formula.	Molecular Weight.	Heat given off, the product being			
			Gaseous	Liquid.	Solid.	Dissolved.
Hydrochloric acid	HCL	36.5	22.			39.3
Hydrobromic acid	HBr	81.	9.5			29.5
Water	H_2O	18.	58.2	69.	70.4	
Hydrogen sulphide	H_2S	34.	4.8			
Nitric acid	HNO_3	63.	34.4	41.6	42.2	48.8
Hyposulphurous acid	$H_2S_2O_3$	114.				67.2
Sulphur dioxide	SO_2	64.	69.2			
Sulphur trioxide	SO_3	80.	91.8		103.6	141.
Sulphuric acid	H_2SO_4	98.		124.	124.8	
Hypochlorous acid anhydride	Cl_2O	86.	−15.2			−5.8
Perchloric acid	$HClO_4$	100.5		−30.8		
Carbon dioxide	CO_2	44.	94.3			
Carbon monoxide	CO	28.	25.8			
Nitrous oxide	N_2O	44.	−20.6	−16.2		
Nitrogen dioxide	NO	30.	−21.6			
Nitrous anhydride	N_2O_3	76.	−22.2			
Nitrogen peroxide	NO_2	46.	−2.6	1.8		
Nitric anhydride	N_2O_5	108.	−1.2	3.6	11.8	28.6
Potassium oxide	K_2O	94.			97.2	164.6
Sodium oxide	Na_2O	62.			100.2	145.2
Antimonous oxide	Sb_2O_3	287.2			167.4	
Antimonic oxide	Sb_2O_5	329.2			228.8	
Potassium chloride	KCl	74.6			105.	100.8
Sodium chloride	$NaCl$	58.5			97.3	96.2
Ammonium chloride	NH_4Cl	53.5			76.7	72.7
Calcium chloride	$CaCl_2$	110.			170.	187.
Potassium sulphide	K_2S	110.2			102.2	112.4
Sodium sulphide	Na_2S	78.			88.4	103.2
Antimony sulphide	Sb_2S_3	335.2			34.	
Ammonium sulphide	$(NH_4)_2S$	68.				56.8
Potassium nitrate	KNO_3	101.1			118.7	
Sodium nitrate	$Na\ No_3$	85.			110.6	
Ammonium nitrate	NH_4NO_3	80.			87.9	
Potassium sulphate	K_2SO_4	174.			342.2	
Sodium sulphate	Na_2SO_4	142.			326.4	
Potassium carbonate	K_2CO_3	138.			278.8	
Sodium carbonate	Na_2CO_3	106.			274.8	
Nitronaphthalene	$C_{10}H_7NO_2$	173.			−14.7	
Binitronaphthalene	$C_{10}H_6(NO_2)_2$	218.			−5.7	
Trinitronaphthalene	$C_{10}H_5(NO_2)_3$	263.			3.3	
Potassium chlorate	$KClO_3$	122.5			94.6	
Ammonia	NH_3	17.	12.2			
Nitrogen sulphide	NS	46.	−19.	−25.4	−31.9	
Cyanogen	CN	26.	−37.3			−33.9
Hydrocyanic acid	HCN	27.	−29.	−23.8		23.4
Potassium cyanide	KCN	65.			30.3	27.4
Acetylene	C_2H_2	26.	−61.4			

HEATS OF FORMATION—*Continued.*

Name.	Formula.	Molecular Weight.	Heat given off, the product being			
			Gaseous	Liquid.	Solid.	Dissolved.
Ethylene	C_2H_4	28.	−15.4			
Methane	CH_4	16.	18.5			
Benzene	C_6H_6	78.	−10.2	−3.2	−0.9	
Terebenthene	$C_{10}H_{16}$	136.	8.6	−17.		
Naphthalene	$C_{10}H_8$	128.			−23.7	
Anthracene	$C_{14}H_{10}$	178.			−42.4	
Methyl alcohol	CH_3OH	32.	53.6	62.		64.
Ethyl alcohol	C_2H_5OH	46.	60.7	70.5		73.
Propyl alcohol	C_3H_7OH	60.		67.		70.
Phenol	C_6H_5OH	94.		34.5	36.8	32.
Glycerine	$C_3H_5(OH)_3$	92.		165.5	169.4	164.
Mennite dulcite	$C_6H_{14}O_6$	172.			320.	315.
Glucoses and isomers	$C_6H_{12}O_6$	180.			306.	303.
Saccharose and isomers	$n(C_6H_{12}O_6)$	n(180.)			n(269.)	
Cellulose (cotton)	$C_6H_{10}O_5$	162.			227.	
Aldehyde	C_2H_4O	44.	50.5	56.5		60.1
Ethyl nitrate	$C_2H_5NO_3$	91.		49.3		50.3
Nitroglycerine	$C_3H_5(NO_2)_3O_3$	227.		98.		
Nitromannite	$C_6H_8(NO_3)_6$	452.			149.	
Mercury fulminate	$C_2N_2O_2Hg$	284.			−62.9	
Nitrocellulose (N_{11})	$C_{24}H_{29}N_{11}O_{42}$	1143.			624.	
Nitrobenzene	$C_6H_5NO_2$	123.		4.2	6.9	
Dinitrobenzene	$C_6H_4(NO_2)_2$	168.			12.7	
Picric acid	$C_6H_2(NO_2)_3OH$	229.			49.1	41.
Potassium picrate	$C_6H_2(NO_2)_3OK$	267.			117.5	107.5
Ammonium picrate	$C_6H_2(NO_2)_3ONH_4$	246.			80.1	71.4
Sodium picrate	$C_6H_2(NO_2)_3ONa$	251.			105.3	98.9
Diazonitrobenzol	$C_6H_5N_3O_3$	167.			−47.4	
Ether	$(C_2H_5)_2O$	74.	65.3	72.		78.
Methyl nitrate	CH_3NO_3	77.		39.9		
Dinitroglycol	$C_2H_4N_2O_6$	152.		66.9		
Propyl glycol	$C_3H_8O_2$	76.		127.		
Nitrocellulose (N_8)	$C_{24}H_{32}N_8O_{36}$	1008.			706.	
Amyl alcohol	$C_5H_{11}OH$	88.	82.3	93.		95.8
Amyl nitrate	$C_5H_{11}NO_3$	133.	7.	71.		
Glycol	$C_8H_6O_2$	62.			111.7	113.4
Sodium oxalate	$(CO_2Na)_2$	134.			313.8	

TABLE III.

SPECIFIC HEATS.

Name.	Formula.	Molecular Weight.	Specific heats referred to One Gram.	Specific heats referred to Molecular Weight.
Sulphur (fused)	S_2	64.	0.203	12.8
Phosphorus	P_4	124.	0.190	11.8
Arsenic	As_2	150.	0.081	12.1
Antimony	Sb_2	244.	0.051	12.4
Carbon	C_2	24.	0.202	4.8
Mercury	Hg	200.	0.033	32.56
Lead	Pb_2	414.	0.031	13.2
Silver	Ag_2	216.	0.057	12.4
Magnesia	MgO	40.	0.244	9.76
Chromic oxide	Cr_2O_3	152.8	0.190	29.00
Aluminum oxide	Al_2O_3	103.	0.217	22.40
Ammonium chloride	NH_4Cl	53.	0.373	20.00
Potassium chloride	KCl	74.6	0.173	12.89
Sodium chloride	NaCl	58.5	0.214	12.5
Barium chloride	$BaCl_2$	207.	0.090	18.6
Calcium chloride	$CaCl_2$	111.	0.104	18.4
Silver chloride	AgCl	143.	0.091	13.1
Potassium sulphide	K_2S	110.	0.091	19.00
Sodium sulphide	Na_2S	78.	0.091	19.00
Iron sulphide	FeS	88.	0.136	11.94
Potassium ferro cyanide	$K_4Fe(CN)_6$	430.	0.280	118.00
Potassium nitrate	KNO_3	101.1	0.239	24.20
Sodium nitrate	$NaNO_3$	85.	0.278	23.70
Barium nitrate	$Ba(NO_3)_2$	261.	0.150	38.00
Strontium nitrate	$Sr(NO_3)_2$	211.	0.180	38.00
Lead nitrate	$Pb(NO_3)_2$	330.	0.110	36.4
Silver nitrate	$AgNO_3$	170.	0.143	24.4
Ammonium nitrate	NH_4NO_3	80.	0.455	36.4
Potassium sulphate	K_2SO_4	174.	0.190	33.2
Sodium sulphate	Na_2SO_4	142.	0.229	32.4
Calcium sulphate	$CaSO_4$	136.	0.180	25.4
Strontium sulphate	$SrSO_4$	183.5	0.140	24.8
Copper sulphate	$CuSO_4$	159.5	0.134	21.4
Potassium bichromate	$K_2Cr_2O_7$	294.	0.187	36.4
Potassium carbonate	K_2CO_3	138.	0.210	30.0
Sodium carbonate	Na_2CO_3	106.	0.270	29.0
Calcium carbonate	$CaCO_3$	100.	0.200	21.0
Barium carbonate	$BaCO_3$	197.	0.110	21.4
Lead carbonate	$PbCO_3$	260.	0.141	39.4
Potassium chlorate	$KClO_3$	122.5	0.210	25.7
Potassium perchlorate	$KClO_4$	138.5	0.190	26.3
Water	H_2O	18.	1.000	18.0
Nitric acid	HNO_3	63.	0.445	28.0
Sulphuric acid	H_2SO_4	98.	0.340	33.4
Benzene	C_6H_6	78.	0.440	34.0
Alcohol	C_2H_5OH	46.	0.595	27.3
Glyceriné	$C_3H_5(OH)_3$	92.	0.591	54.4
Antimony oxide	Sb_2O_3	287.2	0.090	25.85
Silica	SiO_2	60.3	0.195	11.76

Table IV.

DENSITIES AND MOLECULAR VOLUMES.

Name.	Formula.	Molecular Weights, M	Density. D	Molecular Volume in c.c. $\frac{M}{D}$
Sulphur	S_2	64.	2.04	31.36
Carbon	C_2	24.	2.50 diamond 2.27 graphite 1.67 amorph.	6.85 10.66 15.28
Potassium chloride	KCl	74.6	1.94	38.70
Sodium chloride	NaCl	58.5	2.10	27.20
Barium chloride	$BaCl_2$	207.	3.70	56.0
Strontium chloride	$SrCl_2$	158.5	2.80	59.0
Ammonium chloride	NH_4Cl	53.	1.53	35.0
Potassium nitrate	KNO_3	101.	2.06	49.0
Sodium nitrate	$NaNO_3$	85.	2.24	39.0
Barium nitrate	$Ba(NO_3)_2$	261.	3.25	82.0
Lead nitrate	$Pb(NO_3)_2$	330.	4.40	76.0
Silver nitrate	$AgNO_3$	170.	4.35	39.0
Ammonium nitrate	NH_4NO_3	80.	1.71	41.0
Strontium nitrate	$Sr(NO_3)_2$	211.	2.93	71.30
Potassium carbonate	K_2CO_3	138.	2.26	62.0
Sodium carbonate	Na_2CO_3	107.	2.47	43.0
Barium carbonate	Ba_2CO_3	197.	4.30	46.0
Strontium carbonate	$SrCO_3$	147.5	3.62	40.0
Calcium carbonate	$CaCO_3$	100.	2.71	36.0
Potassium sulphate	K_2SO_4	174.	2.66	66.0
Sodium sulphate	Na_2SO_4	142.	2.63	54.0
Barium sulphate	$BaSO_4$	233.	2.45	52.0
Strontium sulphate	$SrSO_4$	183.5	3.59	52.0
Calcium sulphate	$CaSO_4$	136.	2.93	46.0
Potassium chlorate	$KClO_3$	122.5	2.33	52.6
Potassium bichromate	$K_2Cr_2O_7$	294.	2.69	110.0
Antimony oxide	Sb_2O_3	292.	5.53	53.0
Antimony sulphide	Sb_2S_3	334.	4.42	75.0
Calcium oxide	CaO	56.	3.15	18.0
Ammonium sulphate	$(NH_4)_2SO_4$	132.	1.76	75.0
Copper nitrate	$Cu(NO_3)_2$	192.	2.03	94.5
Mercuric oxide	HgO	216.	11.14	19.38
Potassium sulphide	K_2S	110.	2.97	37.0
Sodium sulphide	Na_2S	78.	2.17	36.0
Silica	SiO_2	60.	2.65	23.0
Potassium cyanide	KCN	65.0	1.52	43.0

Table V.

ATOMIC WEIGHTS.

The atomic weights in this table are the International Atomic Weights (1906) modified to make the atomic weight of hydrogen unity.

Element.	Symbol	Atomic Weight.	Element.	Symbol	Atomic Weight.
Aluminum	Al	26.9	Neon	Ne	19.9
Antimony	Sb	119.3	Nickel	Ni	58.3
Argon	A	39.6	Niobium	Nb	93.3
Arsenic	As	74.4	Nitrogen	N	13.9
Barium	Ba	136.4	Osmium	Os	189.6
Beryllium	Be	9.	Oxygen	O	15.9
Bismuth	Bi	206.9	Palladium	Pd	105.7
Boron	B	10.9	Phosphorus	P	30.8
Bromine	Br	79.4	Platinum	Pt	193.3
Cadmium	Cd	111.6	Potassium	K	38.9
Cæsium	Cs	132.	Prascodymium	Pr	139.4
Calcium	Ca	39.8	Radium	Ra	223.3
Carbon	C	11.9	Rhodium	Ro	102.2
Cerium	Ce	139.	Rubidium	Rb	84.8
Chlorine	Cl	35.2	Ruthenium	Ru	100.9
Chromium	Cr	51.7	Samarium	Sm	148.9
Cobalt	Co	58.5	Scandium	Sc	43.8
Copper	Cu	63.1	Selenium	Se	78.6
Erbium	E	164.8	Silicon	Si	28.2
Fluorine	F	18.9	Silver	Ag	107.1
Gadolinium	Gd	155.	Sodium	Na	22.9
Gallium	Ga	69.5	Strontium	Sr	87.
Germanium	Ge	71.9	Sulphur	S	31.8
Gold	Au	195.7	Tantalum	Ta	181.6
Helium	He	4.	Tellurium	Te	126.6
Hydrogen	H	1.	Terbium	Tb	158.8
Indium	In	113.1	Thallium	Tl	202.6
Iodine	I	125.9	Thorium	Th	230.8
Iridium	Ir	191.5	Thulium	Tm	169.7
Iron	Fe	55.5	Tin	Sn	118.1
Krypton	Kr	81.2	Titanium	Ti	47.7
Lanthanum	La	137.9	Tungsten	W	182.6
Lead	Pb	205.4	Uranium	U	236.7
Lithium	L	7.	Vanadium	V	50.8
Magnesium	Mg	24.2	Xenon	Xe	127.
Manganese	Mn	54.6	Ytterbium	Yb	171.7
Mercury	Hg	198.5	Yttrium	Y	88.3
Molybdenum	Mo	95.3	Zinc	Zn	64.9
Neodymium	Nd	142.5	Zirconium	Zr	89.9

TABLE VI.

CONVERSION: METRIC AND ENGLISH UNITS, TEMPERATURES.

English to Metric.		Metric to English.	
To Convert	Multiply by	To Convert	Multiply by
Inches to centimeters	2.539978	Centimeters to inches	0.39370428
Inches to meters..........	0.02539978	Meters to inches.........	39.370428
Feet to meters..........	0.3047973	Meters to feet............	3.280869
Yards to meters.........	0.9143918	Meters to yards..........	1.093623
Miles to kilometers........	1.609329	Kilometers to miles.......	0.6213769
Square inches to square centimeters...........	6.451484	Square centimeters to square inches	0.155003
Square feet to square meters..................	0.09290138	Square meters to square feet....................	10.76410
Square yards to square meters.................	0.8361126	Square meters to square yards.................	1.196011
Cubic inches to cubic centimeters	16.38663	Cubic centimeters to cubic inches................	0.06102537
Cubic feet to cubic meters	0.02831609	Cubic meters to cubic feet.	35.31561
Cubic yards to cubic meters..................	0.7645345	Cubic meters to cubic yards................	1.307985
Quarts, liquid, to liters....	0.9463279	Liters to quarts (liq.).....	1.056716
Gallons (231 cu. in.) to dekaliters.............	0.3785311	Dekaliters to gallons.......	2.641791
Grains to grams.........	0.06479887	Grams to grains.........	15.43236376
Ounces (avoir.) to grams..	28.34951	Grams to ounces (avoir.)..	0.03527398
Pounds (av.) to kilograms.	0.4535922	Kilograms to pounds (av.)	2.20462339
Foot-pounds to kilogrammeters................	0.1382537	Kilogrammeters to foot-pounds................	7.233080
Pounds per sq. in. to kilograms per sq. cent.......	0.0703082	Kilograms per sq. cent. to pounds per sq. in........	14.22309
Pounds per sq. in. to kilograms per sq. decimeter	7.03082	Kilograms per sq. decimeter to pounds per sq. in................	0.1422309

TEMPERATURES.—T_f = temperature Fahrenheit; T_c = temperature centigrade.

Fahrenheit to centigrade, $T_c = \frac{5}{9}(T_f - 32°)$.

Centigrade to Fahrenheit, $T_f = \frac{9}{5}T_c + 32°$.